CALIFORNIA FISH AND GAME

"CONSERVATION OF WILDLIFE THROUGH EDUCATION"

VOLUME 69 OCTOBER 1983 NUMBER 4

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1416 Ninth Street
Sacramento, California 95814

CALIFORNIA FISH AND GAME

VOLUME 69 OCTOBER 1983 NUMBER 4

Published Quarterly by

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DEPARTMENT OF FISH AND GAME

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SEX, AGE, AND SPECIES DIFFERENCES IN DISEASE MORTALITY OF ROSS' AND LESSER SNOW GEESE IN CALIFORNIA: IMPLICATIONS FOR AVIAN CHOLERA RESEARCH [1]

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Age, sex, and body weight of Ross' geese, *Anser rossii,* and lesser snow geese, *Anser caerulescens caerulescens,* that died during disease outbreaks were recorded in the winters of 1975–76 and 1976–77 in California. The same parameters were obtained from Ross' and snow geese trapped during banding operations or shot by hunters. Among adult geese, more males than females died in epizootics (1.8:1, Ross'; 1.3:1, snow) despite nearly equal sex ratios among hunter-killed and trapped birds. Equal sex ratios were found among immature birds that died from disease, but fewer male than female immature geese were trapped or shot by hunters. Immature geese of both species were more prevalent among birds that died at the most severe stage of an epizootic than either earlier or later stages. These data indicate that mortality from disease may not be equal across all sex and age classes of geese. Avian cholera, *Pasteurella multocida,* accounted for 94% of disease mortality of Ross' and snow geese in 1975–76 and 1976–77 in California. Variability in host vulnerability and the geographic patterns of occurrence of epizootics suggest that "carriers" of avian cholera occur in populations of Ross' and snow geese in western North America. "Avian cholera" outbreaks may result from synergism of bacteria with pollutants and/or naturally occuring environmental factors.

INTRODUCTION

Avian cholera, caused by the bacterium, *Pasteurella multocida,* has been known as a disease in birds (primarily of domestic poultry) for nearly 200 years (Rosen 1971). Among wild birds, waterfowl appear to be particularly vulnerable to avian cholera (Rosen 1969, Wobeser 1981). The disease was first reported in wild waterfowl in North America in 1944 (see Friend 1981 for review). In recent years, thousands of ducks and geese have died annually and, in California, avian cholera has become a major cause of natural mortality in wintering waterfowl (Rosen 1971, Titche 1979). Comparisons of vulnerability to disease among species often ignore age and sex composition of host populations (e.g. Hazelwood *et al.* 1968, Rosen 1969, 1972) and assessment of the impact of avian cholera on the population dynamics of waterfowl has not been determined. Basic population and physiological parameters of birds that died from avian cholera, such as age, sex, and body weight are only occasionally reported (Petrides and Byrant 1951; Korschgen, Gibbs, and Mendall 1978). I obtained such data from Ross' geese, *Anser rossii,* and lesser snow geese, *Anser caerulescens caerulescens,* that died during disease outbreaks throughout northern and central California during the atypically dry winters of 1975–76 and 1976–77. In addition, comparable information was obtained from free-living geese of both species.

Evaluation of data obtained in this study indicated that mortality from disease outbreaks in California is not equal among different sex and age classes of geese. These data, together with observations of host behavior, are reported for consid-

[1] Accepted for publication May 1982.

eration by investigators of avian cholera. I offer several suggestions for future research in the hope that they will lead to improved management and control of disease in wintering waterfowl.

METHODS

Dead Ross' and lesser snow geese were collected from seven sites in the Central Valley of California (three in Merced, two in Colusa, one in Butte, and one in Glenn counties) where disease outbreaks occurred during winter (December to February) in 1975–76 and 1976–77. Birds also were obtained from epizootics at Tule Lake National Wildlife Refuge in northeastern California in the spring (March and April) of both 1976 and 1977 and during the fall (November) of 1976. In Spring 1976, birds were collected whenever dead geese accumulated along lake shores (1 to 4-day intervals). A mucoid nasal discharge, which is a sign of avian cholera (Rosen 1971), was evident on most (80–90%) dead geese. Emaciated birds were rarely encountered, did not exhibit nasal discharge, and were not included in samples of diseased geese. Crippled birds were also excluded from samples. Behavior of dying geese and reactions of nearby healthy birds were recorded during epizootics.

I used two sources of data to estimate sex ratios of "healthy" birds from wild populations of Ross' and snow geese: 1) During the fall migration seasons of 1975 and 1976, Ross' and snow geese were trapped with cannon nets at roosting sites along shores of lakes in west-central Saskatchewan in Canada. Nearly all Ross' geese and most snow geese from these areas migrate to California (Bellrose 1980). Behavioral interactions which might bias representation of population sex structure of captured birds (Raveling 1966) were minimal because trap sites were not baited and geese were captured soon after arrival at roost sites; 2) Birds shot by hunters in California were examined at commercial waterfowl picking plants in the town of Tulelake and at state operated hunter checking stations of state and federal wildlife refuges in the Central Valley.

Plumage characteristics were used to identify age of "diseased", shot, and trapped geese. Sex was determined from cloacal examination. Birds were weighed with a Pesola spring scale.

In spring, species and age composition were determined from field observations of free-living birds at Tule Lake, where flocks of white geese were composed of both Ross' and snow geese. Weekly estimates of relative species abundance were calculated by weighting proportions of each species present in randomly sampled flocks by flock size (cf. McLandress 1979). Percentages of immature birds of each species were derived from samples of geese whose plumage characters were examined with a spotting scope (cf. Lynch and Singleton 1964).

RESULTS

Observations of Dying Geese

Dying geese (n=approximately 50) were seen in both years of study at all epizootic sites where large concentrations of "healthy" Ross' and snow geese were present. The earliest observable sign which indicated to me that geese were sick was when nearby healthy birds rapidly swam (or ran) away from the diseased birds; this occurred 30 min or less before death (n=8 complete observations). Healthy geese retreated to at least 30 m from birds which were dying.

In this earliest stage, dying geese swam in circles or, if on land, slumped to the ground with necks swaying from side to side and heads tilted upward (Figure 1*a*). Shortly thereafter (2–10 min), they began flapping their wings convulsively and were unable to swim, walk, or hold their heads erect (Figure 1*b*). Most observations of dying geese began at this stage because it was so conspicuous. Just before death, geese quivered violently and assumed a stiff posture with necks either stretched downward or over their backs. Often, their wings were partially extended (Figure 1*c*). Healthy geese seldom remained nearer than 3 m to dead birds (approximately 50 observations).

Differential Mortality

Among Epizootics

Sex composition data for adult and immature Ross' and snow geese obtained from trapped birds were not significantly different from comparable sex composition data for birds shot by hunters in either year of study (all $\underline{X}^2$ tests, $\underline{P} > 0.1$). Thus, birds obtained from the two methods were combined for further analyses. Sex ratios of trapped and hunter-killed geese of both species were even among adults in both years and among immatures in 1975–76 (Table 1). In 1976–77, however, there was a preponderance of females among trapped and hunter-killed immature Ross' and snow geese.

TABLE 1. Sex Ratios of Ross' and Lesser Snow Geese (Males Per Female (N)) that were Trapped or Killed by Hunters on Migration and Wintering Areas in California.

	Lesser snow geese		*Ross' geese*	
Year/Source	*Adults*	*Immature*	*Adults*	*Immature*
1975–76				
Trapped (Saskatchewan)	1.1 (31)	1.6 (21)	1.0 (410)	0.9 (287)
Shot (California)	1.1 (265)	0.9 (626)	1.2 (95)	1.1 (122)
Total	1.1 (296) ns [1]	0.9 (647) ns	1.1 (505) ns	1.0 (409) ns
1976–77				
Trapped (Saskatchewan)	1.4 (41)	0.6 (52)	1.0 (488)	0.6 (99)
Shot (California)	1.1 (527)	0.8 (1238)	1.0 (120)	0.7 (82)
Total	1.1 (568) ns	0.8 (1290) **	1.0 (608) ns	0.6 (181) **

[1] Significance of $\underline{X}^2$ comparison of trapped and shot geese with 50:50 sex ratio : ns not significant, ns+ $\underline{P} < 0.1$, * $\underline{P} < 0.05$, ** $\underline{P} < 0.01$.

Males were more prevalent in samples of dead birds from epizootics than among trapped and shot birds for adult and immature geese of both species, although differences were not statistically significant for immature geese in 1975–76 nor adult snow geese in 1976–77 (Table 2). [Note: data from dead geese obtained in the Central Valley each year were pooled for analysis because there were no significant differences in sex composition of birds among sites where epizootics occurred (all $\underline{X}^2$ tests, $\underline{P} > 0.1$)]. The preponderance of males among dead adult geese was more pronounced in 1975–76 than in 1976–77 in both species for all comparable locations and total differences were statistically significant for Ross' geese ($\underline{X}^2 = 4.62$, $\underline{P} < 0.05$, Table 2). Sex ratios were nearly even among dead immature geese and did not differ significantly between years for either species.

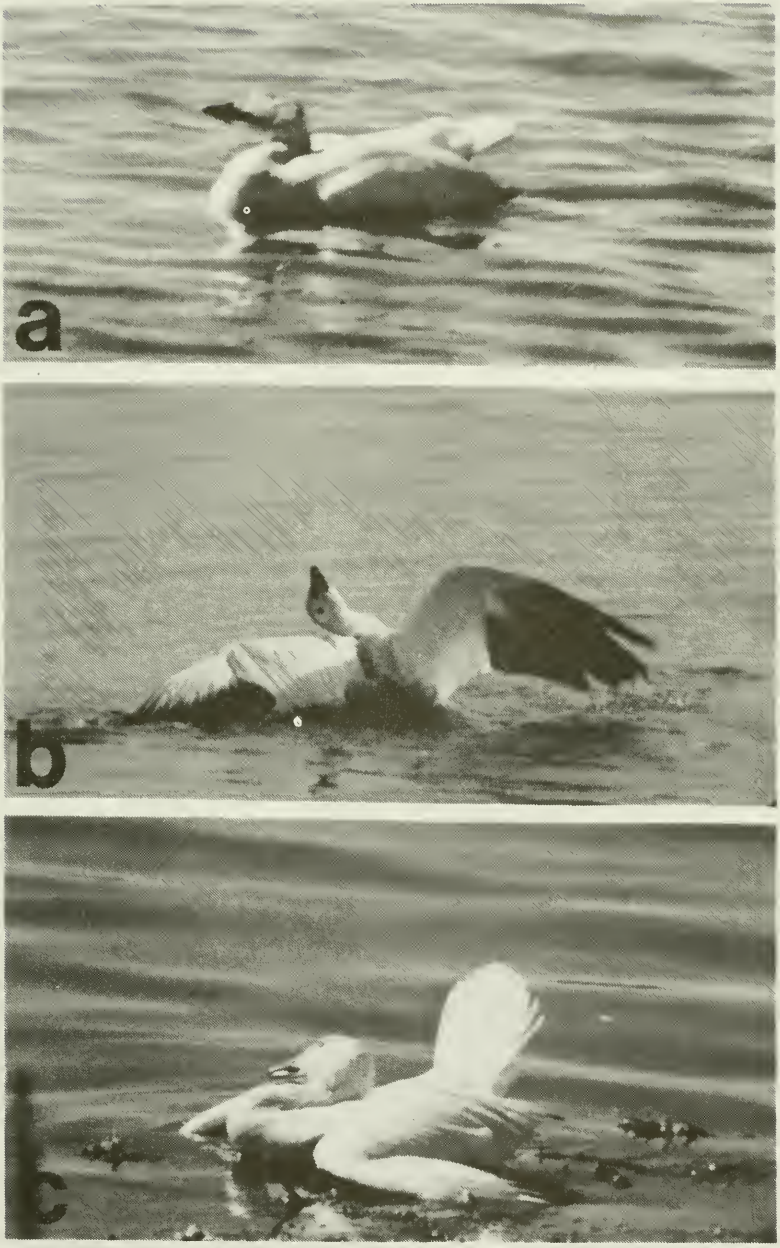

FIGURE 1. Snow goose dying from avian cholera: a) swimming in circles, b) wing-flapping, c) quivering.

Within an Epizootic

A sufficient number of dead birds was obtained from an epizootic at Tule Lake in spring 1976 to allow a more detailed analysis of differential vulnerability by

sex, age, and species. A period of high mortality lasted for 4 d (25 to 28 March) during which 394 dead Ross' and snow geese were retrieved from lake roosting areas. This was 52% of all dead birds found during the 29-d period of study (9 March to 6 April) and represented a 7-fold greater number of dead geese found per day than either before or after the 4-d period.

TABLE 2. Sex Ratios of Ross' and Lesser Snow Geese (Males Per Female (N)) that Died During Epizootics on Migration and Wintering Areas in California.

	Lesser snow geese		*Ross' geese*	
Year/Location	*Adults*	*Immature*	*Adults*	*Immature*
1975–76				
Central Valley (Dec.–Feb.)	2.0 (62)	1.1 (47)	2.7 (44)	1.3 (23)
Tule Lake (Mar.–Apr.)	1.8 (259)	1.1 (182)	1.9 (183)	1.0 (115)
Total	1.8 (321) ** [1]	1.1 (229)ns	2.0 (227) **	1.1 (138)ns
1976–77				
Tule Lake (Nov.)	1.2 (39)	1.1 (54)	1.8 (14)	1.3 (7)
Central Valley (Dec.–Feb.)	1.4 (43)	1.2 (43)	1.4 (306)	1.3 (112)
Tule Lake (Mar.–Apr.)	1.4 (66)	1.5 (27)	1.4 (110)	1.4 (17)
Total	1.3 (148)ns	1.2 (124) *	1.4 (430) **	1.3 (136) **

[1] Significance of $\underline{X}^2$ comparison of geese that died from disease with trapped and shot birds in Table 1: symbols as in Table 1.

The sex composition of dead geese examined during the outbreak at Tule Lake was similar to other epizootics in the winter of 1975–76 (Table 2). More males than females died among adult but not among immature geese of both species. There were no significant differences in either the disparate sex ratios of adult or the equal sex ratios of immature geese that died before, during or after the period of highest mortality of the outbreak (Table 3). Samples may have been too small for their detection, however. Because there was no difference in vulnerability between sexes among immature geese in 1975–76 (Table 2), male and female immature geese were pooled for further analyses. Immature geese of both species were more prevalent among birds dying during the period of highest mortality than at either earlier or later stages of the epizootic. Examination of free-living birds in spring revealed that 39% of 4,853 snow geese and 35% of 936 Ross' geese were immature. The ratio of immatures to adult females was similar between samples of dead and free-living birds (50% of adults were assumed to be females, Table 1) both before and after the period of highest mortality (snows: $\underline{X}^2 = 0.02$ before, $\underline{X}^2 = 1.46$ after; Ross': $\underline{X}^2 = 1.55$ before, $\underline{X}^2 = 1.19$ after; all tests $\underline{P} > 0.10$). In contrast, there was a greater proportion of immature birds relative to adult females among dead geese during the period of high mortality than was indicated in the living population (snows: $\underline{X}^2 = 16.95$, Ross': $\underline{X}^2 = 23.51$; both tests $\underline{P} < 0.01$). During the same period, the relative abundance of immature geese to adult males among dead geese was similar to that of the free-living population (snows: $\underline{X}^2 = 2.21$, Ross': $\underline{X}^2 = 1.17$; both tests $\underline{P} > 0.10$) reflecting a near equal vulnerability to disease. Thus, mortality of immature geese appeared related to the severity of the epizootic and was highest when the greatest numbers of birds were dying. Adult female geese were less vulnerable than birds of all other age/sex categories.

TABLE 3. Age Composition and Sex Ratios (Males Per Female) of Ross' and Lesser Snow Geese that Died During an Epizootic in Spring 1976 at Tule Lake, California.

Phase of outbreak	*N*	*% Immature*[1]	*Sex Ratio*	
			Adult	*Immature*
		Lesser snow geese		
Early (9–24 March)	177	32** [2]	1.8ns	1.0ns
Mortality Peak (25–28 Mar.)	195	51ns +	1.7ns	1.3ns
Late (29 Mar.–6 Apr.)	79	39	2.1	0.8
		Ross' geese		
Early	70	26**	1.3ns+	0.8ns
Mortality Peak	199	47*	2.4ns	1.1 [3]
Late	38	21	2.0	0.5

[1] See text for estimates of percent immatures in free-living population.
[2] Significance of $\underline{X}^2$ comparison between geese that died in adjacent phases of outbreak: symbols as in Table 1.
[3] Insufficient sample in late phase for comparison.

Species Vulnerability

Through spring, the percentage of Ross' geese in flocks of white geese at Tule Lake gradually increased; 33% on 17 March, 40% on 25 March, 45% on 3 April. From these data and population age structures of each species, ratios of snow to Ross' geese were calculated for both adult and immature birds for each date (Table 4). These ratios were used to calculate expected values for statistical comparison to the numbers of dead geese of each species by age/sex category.

TABLE 4. Relative Vulnerability to Disease of Ross' and Lesser Snow Geese by Age and Sex During an Epizootic in Spring 1976 at Tule Lake, California.

Phase of outbreak	*Snow geese per Ross' goose among:*				
	Dead adults			*Dead immatures*	
	Males	*Females*	*Exp*[1]	*Sexes combined*	*Exp*[1]
Early (9–24 Mar.)	2.6ns [2]	1.8ns	1.9	3.2ns	2.3
Mortality Peak (25–28 Mar.)	0.8 **	1.1ns	1.4	1.1**	1.7
Late (29 Mar.–6 Apr.)	1.6ns	1.5ns	1.1	3.9 **	1.4
Total	1.4ns	1.4ns	1.5	1.6ns	1.7

[1] Expected ratios calculated from population composition determined from field observations; see text.
[2] Significance of $\underline{X}^2$ comparison of geese that died from disease with values calculated from expected ratios: symbols as in Table 1.

Relative vulnerability of Ross' and snow geese was not consistent among age/sex categories of birds found during the outbreak at Tule Lake. Among dead adult female geese obtained during each phase of the epizootic, the relative abundance of Ross' and snow geese was not different than that calculated from the free-living population (Table 4). Among dead adult male and immature geese, however, Ross' were more prevalent during the period of highest mortality than expected from their representation in the free-living population. But, relatively more snow than Ross' adult male and immature geese died in the less severe phases of the outbreak, although statistical differences were found only for immatures. As a result, differential species vulnerability was not significant for any age/sex category when birds that died in all phases of the epizootic were combined (expected composition was weighted by adding expected values calculated for each phase of the outbreak).

Body Weights

In 1976–77, many dead geese were obtained from epizootics during the

hunting season. Body weights of these geese were not significantly different (all t-tests, $P > 0.1$) from weights of birds shot by hunters for any age/sex category (Table 5).

TABLE 5. Comparison of Body Weights in Kg ($\bar{X} \pm SE$ (N)) between Lesser Snow and Ross' Geese that Died from Disease and Those Shot by Hunters in California in 1976–77.

Location/Cause of death	*Adult*		*Immature*	
	Male	*Female*	*Male*	*Female*
	Lesser snow geese			
Tule Lake (Nov.)				
Disease	2.30 ± 0.03 (19)	2.16 ± 0.04 (16)	2.04 ± 0.07 (18)	1.90 ± 0.04 (14)
Shot	2.35 ± 0.02 (76)	2.13 ± 0.02 (77)	2.08 ± 0.01 (291)	1.90 ± 0.01 (357)
Central Valley (Dec.–Jan.)				
Disease	2.26 ± 0.04 (22)	2.09 ± 0.06 (17)	1.98 ± 0.07 (23)	1.76 ± 0.07 (18)
Shot	2.26 ± 0.02 (178)	2.01 ± 0.02 (158)	1.97 ± 0.02 (194)	1.78 ± 0.01 (260)
	Ross' geese			
Tule Lake (Nov.)				
Disease	1.62 ± 0.05 (11)	1.40 ± 0.11 (5)	1.45 ± 0.05 (7)	1.37 ± 0.08 (2)
Shot	1.61 ± 0.01 (42)	1.44 ± 0.03 (29)	1.43 ± 0.02 (32)	1.28 ± 0.02 (39)
Central Valley (Dec.–Jan.)				
Disease	1.48 ± 0.03 (28)	1.33 ± 0.04 (12)	1.30 ± 0.04 (13)	1.17 ± 0.03 (14)
Shot	1.42 ± 0.03 (33)	1.23 ± 0.03 (31)	1.22 ± 0.03 (9)	1.18 ± 0.03 (13)

DISCUSSION

Ross' and lesser snow geese are common, closely related, and sympatric in California, thus providing a unique situation for experiment replication in a field study. Although both species are polymorphic, they are almost exclusively white in California (McLandress and McLandress 1979) and dead birds are highly conspicuous. Thus, it is unlikely that many geese were undetected in searches for dead birds during this study.

The majority of dead Ross' and snow geese obtained from epizootics in California probably died from avian cholera. Most geese showed signs consistent with (although not exclusive to) the disease. In the two years of this study, the California Department of Fish and Game, Wildlife Investigation Laboratory examined 526 snow geese that died in similar epizootics in California. *P. multocida* was present in 91% of these geese, 3% were shot, 3% died of lead poisoning, and 3% died of "other" causes (two had botulism and the remaining geese died from undetermined causes; emaciated birds were reported only in the "other" category). In addition, 50 Ross' geese were examined; 88% died of avian cholera and 12% were shot. A few (< 10-E. O'Neill, U.S. Fish and Wildlife Service, and D. Becker, Calif. Dept. Fish and Game, pers. commun.) of the geese which were examined in my study were sent to state or federal pathology laboratories and *P. multocida* was found in all specimens. Undoubtedly, some birds which I examined died of other causes but these were unlikely to have caused consistent patterns of adult male predominated differential mortality. Birds which were shot and erroneously classified as diseased geese should have exhibited equal sex ratios (Table 1). In a study of mallards, *Anas platyrhynchos*, acute lead toxicity affected sexes differentially, but males were more vulnerable only when females were hyperphagic in spring (Bellrose 1959). Other diseases which exhibit similar signs (e.g. duck plague-Leibovitz 1971, Friend and Pearson 1973)

have not been reported in wild populations of waterfowl in California, although extensive laboratory tests are required for diagnosis (M. Friend, U.S. Fish and Wildlife Service, pers. commun.).

Behavioral Avoidance

Avoidance of dead or dying geese by healthy birds may reduce exposure to disease organisms (see Alexander 1974:330). Inhalation of water aerosols created by wing-flapping birds has been postulated as a potential route for the transmission of avian cholera (Rosen 1971). Convulsing, dying geese might create potent aerosols. Also, I observed that some of the mucoid nasal discharge, which contains tremendous numbers of bacteria (Rosen 1971), adhered to the heads and bills of dead geese. Current management practice of picking up dead birds is intended to prevent the spread of disease to avian and mammalian scavengers, to eliminate any decoy effect which might lure more waterfowl into the general area (Rosen 1971), and to remove the source for contamination of the water (Titche 1979, Wobeser 1981). When snow and Ross' geese were picked up, however, mucus dripped from the dead birds into the water. This may aid dispersal of bacteria. Procedures of picking up carcasses might be improved if measures were taken to reduce loss of mucus (such as placing plastic bags over the heads of dead birds). Any possible advantage to healthy geese from their avoidance of dead Ross' and snow geese could be tested by replacing dead birds with appropriately shaped, white artificial carcasses.

Differential Mortality

Changes in virulence of *P. multocida* have been demonstrated in other studies (see Rosen 1971, Wobeser 1981 for reviews). Differential mortality may be due to, or compounded by, these changes. Bacterial virulence could be affected by a variety of factors which differ between sexes or between adult and young birds (e.g. hormone levels, metabolic processes, etc.). Conclusions of previous studies concerning species differences in vulnerability to avian cholera (e.g. Petrides and Byrant 1951, Rosen 1969, Hazelwood *et al.* 1978) appear justified, but may be complicated by the severity of outbreaks and by age and sex differences in mortality as indicated in this study. Sex and age of hosts and relative severity of die-offs should be reported in future studies of avian cholera.

Poor physical condition is often mentioned in discussions of susceptibility of waterfowl to avian cholera (Petrides and Byrant 1951; Vaught, McDougle, and Burgess 1967; Rosen 1971; Korschgen *et al.* 1978). Body weights of geese which died from disease, however, were not different than weights of birds killed by hunters. Possibly, differences in body condition were subtle and not reflected by body weight (see also Rosen 1969).

Localized Occurrence of Epizootics

Nearly every year since 1944, extensive outbreaks of avian cholera have occurred in the Central Valley of California (Titche 1979, Friend 1981). There are, however, areas within the Central Valley in which major die-offs have not been recorded despite large concentrations of waterfowl (e.g. Gray Lodge Wildlife Management Area, Rosen 1971; Los Banos W.M.A., J. Cawthon, Calif. Dept. of Fish and Game, pers. commun.). Similarly, avian cholera epizootics have not been noted in staging populations of waterfowl in spring at Summer Lake,

Oregon (B. Claggett, Oregon Dept. of Fish and Game, pers. commun.), despite massive die-offs at Tule Lake which is only 130 km southwest of Summer Lake. Rosen (1971) suggested that this phenomenon contradicted the proposed existence of "carriers" of *P. multocida* within waterfowl populations (Vaught *et al.* 1967) and hypothesized that bacteria came from other sources which persisted at locations of repeated outbreaks (enzootic focii). It is unlikely, however, that male and female geese experience differences in contacting disease organisms in wintering areas. Near equal sex ratios among adults were found among trapped and hunter-killed birds, which would be expected for long-lived monogamous species such as Ross' and snow geese. Also, there was no evidence of differential migration or local movement of sexes for either species from a concurrent study of individually identifiable neck-collared geese (unpubl. data). Mated pairs of lesser snow geese remain intact, and young usually stay with their parents in winter (Prevett and MacInnes 1980). Therefore, it is unlikely that distorted sex ratios among dead geese were the result of differential exposure to bacteria at enzootic focii on wintering areas.

Movements of individually marked Ross' and snow geese between sites which had severe outbreaks and those that were virtually disease-free were recorded frequently in both years of this study (unpubl. data). These areas were often less than 30 km apart. Also, in areas where epizootics occurred, dead birds were often concentrated on specific ponds (typically those with poor water flow—see also Wobeser 1981).

Populations of lesser snow and Ross' geese probably do contain individuals which harbor *P.multocida* (see also Wobeser 1981). This would provide a plausible explanation for the spread of avian cholera among wintering areas and along migration routes of these species (Friend 1981). Indirect evidence of living carriers of *P.multocida* has been found in a small percentage of a variety of waterfowl (Vaught *et al.* 1967, Donahue and Olson 1969, Korschgen *et al.* 1978). Despite chronic and frequently extensive outbreaks of avian cholera in California, many Ross' and snow geese that come in contact with disease organisms probably do not die and some may carry bacteria. Harshfield (1965) found that chickens can carry *P.multocida* for at least a year. Under appropriate conditions, bacteria could kill carriers, other birds infected by carriers, or both (see also Vaught *et al.* 1967). Procedures to detect bacteria in "healthy" birds should be improved because of the potential inadequacy of present methods (Titche 1979, Wobeser 1981).

Synergism

Avian cholera outbreaks may be affected by environmental factors acting to change bacterial virulence or host immunity, or both. Inclement weather and conditions which lead to crowding (such as drought) are examples (Vaught *et al.* 1967), but these factors may only serve to intensify effects of the disease. Pesticides and avian cholera may act in a synergistic manner (Friend and Trainer 1970). Variation in steroid and lipid metabolism affect concentration of organochlorines (Kupfer 1967, Tinsley and Lowry 1969) and might explain differential mortality of birds by age, sex or species. If synergistic factors affect hosts or bacteria, it would not be surprising to find other diseases contributing to "avian cholera" epizootics (e.g. Wobeser 1981:57). Gradual expansion in the range of locations of avian cholera epizootics in North American waterfowl populations

over the past 35 years (see Friend 1981 for review) may well be the result of habitat deterioration and increasing environmental pollution. "Natural" environmental factors such as water quality, trace elements and/or minerals may also be involved in disease outbreaks. Conditions necessary for outbreaks of avian cholera might be identified by comparison of local habitat factors between epizootic sites and areas which are disease-free.

Potential synergists of waterfowl diseases which should be investigated are lead and iron. Because toxicity of ingested lead shot was identified as a significant cause of mortality to waterfowl (Bellrose 1959), "non-toxic" or "steel" (iron) shot has been substituted for lead shot at numerous hunting areas in North America. Direct toxicity of ingested lead shot is much greater than iron (Irby, Locke, and Bagley 1967) but, there is considerable evidence in man and a variety of other animals that vulnerability to disease is enhanced by both lead (Chisholm 1971) and iron (Weinberg 1974, Kluger and Rothenburg 1979). Waterfowl could obtain soluble iron from reducing environments (e.g. poorly drained alkaline soils or water, Bear 1955), lead from automobile emissions (Hirao and Patterson 1974), or either lead or iron from ingested shot. Thus, availability of natural or anthropogenic lead and iron and their effect on diseases of waterfowl require careful study.

ACKNOWLEDGMENTS

This project was funded by Canadian Wildlife Service (CWS) contract #OSZ5-0272 to RIM Ecology Ltd (RIM). For assistance and information, I am grateful to: M. Barbour, R. Fields, J. Helvie, L. Littlefield, M. Miller, and E. O'Neill (U.S. Fish and Wildlife Service-USFWS), D. Becker, B. Browning, J. Cawthon, D. Connelly, J. Cowan, M. Fountain, F. Kozlick, R. LeDonne, L. Nelson (Calif. Dept. Fish and Game-CFG), B. Claggett (Oregon Dept. Fish and Game), R. Boch (Winema Lodge, Tulelake) and Landowners: B. Crane, F. Flynn, and J. Gallo (Merced, Calif.). R. and T. Eastman and the D. Grimm family, owners of commercial waterfowl picking plants in Tulelake, and personnel of state operated hunter checking stations allowed examination of geese shot by hunters. I am grateful to N. Lieman (Nebraska Game and Fish), R. Isbister, D. Nieman, and J. Smith (CWS) who were instrumental in trapping geese. Special thanks to I. McLandress (RIM) and T. Aldrich, C. Ely, S. Jang, D. Judge, and B. Gray-Aldrich (Univ. of Calif. at Davis-UCD) for their help in collecting field data and laboratory analyses. I benefited from discussion with D. Jessup (CFG), T. Barry, and A. Dzubin (CWS). D. Raveling, D. Anderson, C. Toft (UCD), G. Wobeser (Univ. of Saskatchewan, Saskatoon), and M. Friend (USFWS) provided valuable criticisms of early drafts.

LITERATURE CITED

Alexander, R. D. 1974. The evolution of social behavior. Annu. Rev. Ecol. Syst., 5: 325-383.

Bear, F. E. 1955. Chemistry of the soil. Reinhold Publ. Corp. New York. 373p.

Bellrose, F. C. 1959. Lead poisoning as a mortality factor in waterfowl populations. Ill. Nat. Hist. Surv. Bull., 27: 235-288.

———. 1980. Ducks, geese, and swans of North America. Stackpole Books, Harrisburg, Pa. 540p.

Chisholm, J. J., Jr. 1971. Lead poisoning. Sci. Am., 224(2): 15–23.

Donahue, M. M., and L. D. Olson, 1969. Survey of wild ducks and geese for *Pasteurella* spp. Bull. Wildl. Dis. Assoc., 5: 201–205.

Friend, M. 1981. Waterfowl diseases—Changing perspectives for the future. Int. Waterfowl Symp., 4: 189–196.

Friend, M., and G. L. Pearson. 1973. Duck plague (duck virus enteritis) in wild waterfowl. U. S. Dep. Inter., Bur. Sport Fish. and Wildl., 16p.

Friend, M., and D. O. Trainer. 1970. Some effects of sublethal levels of insecticides on vertebrates. J. Wildl. Dis., 6: 335–342.

Harshfield, G. S. 1965. Fowl cholera. Pages 359–373 *in* H. E. Biester and L. H. Schwarte, eds. Diseases of poultry. Iowa State Univ., Ames. 1–1382.

Hazelwood, R. M., A. F. Oddo, R. D. Pagan, and R. G. Botzler. 1968. The 1975–76 avian cholera outbreaks in Humboldt County, California. J. Wildl. Dis., 14: 229–232.

Hirao, Y., and C. C. Patterson. 1974. Lead aerosol pollution in High Sierra overrides natural mechanisms which exclude lead from a food chain. Science, 184: 982–992.

Irby, H. D., L. N. Locke, and G. E. Bagley. 1967. Relative toxicity of lead and selected substitute shot types to game farm mallards. J. Wildl. Manage., 31: 253–257.

Kluger, M. J., and B. A. Rothenburg. 1979. Fever and reduced iron: their interaction as a host defense response to bacterial infection. Science, 203: 374–376.

Korschgen, C. E., H. C. Gibbs, and H. L. Mendall. 1978. Avian cholera in eider ducks in Maine, J. Wildl. Dis., 14: 254–258.

Kupfer, D. 1967. Effects of some pesticides and related compounds on steroid function and metabolism. Resid. Rev., 19: 11–30.

Leibovitz, L. 1971. Duck Plague. Pages 22–33 *in* J. W. Davis, R. C. Anderson, L. Karstad, and D. O. Trainer, eds. Infectious and parasitic diseases of wild birds. Iowa State Univ., Ames. 1–344.

Lynch, J. J., and J. R. Singleton. 1964. Winter appraisals of annual productivity in geese and other water birds. Wildfowl Trust Ann. Rept., 15: 114–126.

McLandress, M. R. 1979. Status of Ross' geese in California. Pages 255–265 *in* R. L. Jarvis and J. C. Bartonek, eds. Management and biology of Pacific Flyway geese. O.S.U. Book Stores, Inc., Corvallis. 1–346.

McLandress, M. R., and I. McLandress. 1979. Blue-phase Ross' geese and other blue-phase geese in western North America. Auk, 96: 544–550.

Petrides, G. A., and C. R. Byrant. 1951. An analysis of the 1949–50 fowl cholera epizootic in Texas panhandle waterfowl. Trans. North Amer. Wildl. Conf., 16: 193–216.

Prevett, J. P., and C. D. MacInnes. 1980. Family and other social groups in snow geese. Wildl. Monogr., 71: 46p.

Reveling, D. G. 1966. Factors affecting age ratios of samples of Canada geese caught with cannon-nets. J. Wildl. Manage., 30: 682–691.

Rosen, M. N. 1969. Species susceptibility to avian cholera. Bull. Wildl. Dis. Assoc., 5: 195–200.

_____. 1971. Avian cholera. Pages 59–74 *in* J. W. Davis, R. C. Anderson, L. Karstad, and D. O. Trainer, eds. Infectious and parasitic diseases of wild birds. Iowa State Univ., Ames. 1–344.

_____. 1972. The 1970–71 avian cholera epornitic's impact on certain species. J. Wildl. Dis., 8: 75–78.

Tinsley, I. J., and R. R. Lowry. 1969. Nutritional interactions and organochlorine insecticide activity. Ann. N. Y. Acad. Sci., 160: 291–298.

Titche, A. R. 1979. Avian cholera in California. Calif. Dept. Fish and Game, Wildl. Manage. Br. Admin. Rept., No. 79-2: 49p.

Vaught, R. W., H. C. McDougle, and H. H. Burgess. 1967. Fowl cholera in waterfowl at Squaw Creek National Wildlife Refuge, Missouri. J. Wildl. Manage., 31: 248–253.

Weinberg, E. D. 1974. Iron and susceptibility to infectious disease. Science, 184: 952–956.

Wobeser, G. A. 1981. Diseases of wild waterfowl. Plenum Press. New York. 300p.

Calif. Fish and Game 69(4): 207–216 1983

THE MOVEMENT AND HOMING OF SMALLMOUTH BASS, *MICROPTERUS DOLOMIEUI*, IN LAKE SAMMAMISH, WASHINGTON [1]

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Smallmouth bass were tagged and released at new locations between 0.8 to 11.3 km away from the initial capture location on the lake. The recaptured bass showed a homing tendency with 41% returning to the site of capture, 38% were apparently on their way back to the point of capture, and only 21% showed a sedentary response by staying in the new release area. Smallmouth tagged and released at the site of capture showed a definite affinity for a home area, with 81% recaptured in the area of capture and release. Of the 19% that moved out of this area, 4.8 km was the farthest distance any fish moved.

The home range tendency of smallmouth bass has potential management implications when considering expanding a smallmouth fishery within a large lake, when stocking a lake for the first time with smallmouth bass, or when evaluating bass tournament release procedures.

INTRODUCTION

Lake Sammamish, a large mesotrophic lake (2000-ha) in western Washington, presently supports a significant population of smallmouth bass, *Micropterus dolomieui*, in addition to other game fish.

Largemouth bass, *Micropterus salmoides*, was the only documented black bass species inhabiting Lake Sammamish between the early 1900's and 1960. The unsanctioned introduction of smallmouth bass into Lake Sammamish occurred sometime in the mid-1960's. By 1973 they began showing up in angler catches and now appear to be the dominant bass species in both numbers and lake area occupied (Pflug 1981).

Smallmouth bass have been studied throughout much of North America (Watson 1965, Forney 1972, Coble 1975, Woodbury 1975, Schneberger 1977). Henderson and Foster (1956) investigated age, growth, movements, and spawning requirements of smallmouth bass in the Columbia River near Richland, Washington. Additional studies of smallmouth bass spawning and movements in the mid-Columbia River area have been performed (Montgomery and Fickeisen 1978; Montgomery, Fickeisen and Becker 1980), while Munther (1970) studied the movement and distribution of smallmouth in the middle Snake River. These studies were conducted on the Columbia River system, located in the eastern portion of Washington state. This study is the first research devoted exclusively to natural lake-dwelling smallmouth in Washington state.

Many of Washington's lowland lakes are inhabited by largemouth bass, but only a few, such as Lake Sammamish, support smallmouth bass. However, a large number of Washington's lowland lakes are mesotrophic and ideally suited

[1] Part of a thesis submitted by the senior author to the University of Washington in partial fulfillment of the master of science degree. Accepted for publication June 1982.

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to support smallmouth bass. The potential exists for the successful introduction of smallmouth bass into a number of carefully selected Washington lakes that exhibit the proper smallmouth habitat requirements. When transplanting any fish it can be a valuable management tool to know the potential movement tendencies of the fish involved. Therefore, this study was designed to investigate the movement and homing tendencies of smallmouth bass within Lake Sammamish.

MATERIALS AND METHODS

Lake Sammamish was subdivided into 23 littoral sections of various sizes. Sectional boundaries were established where visual changes occurred in the littoral habitat type such as depth profile transition, presence or absence of aquatic vegetation, and littoral substrate changes.

Electrofishing and hook and line sampling were the two methods used to collect smallmouth bass in Lake Sammamish. These sampling techniques are the most effective methods for securing large numbers of live smallmouth bass (Bennett 1970). Smallmouth bass were found in abundance throughout the littoral areas of the lake at night. As a result, electrofishing was conducted nocturnally to increase effectiveness. Hook and line sampling typically occurred diurnally throughout the spring and summer months and usually involved artificial lures. The use of these two sampling methods reduced sampling biases such as size selectivity. Collections were made between March and September of 1979 and 1980.

This study utilized an alternating current electrofishing boat designed and constructed specifically for water exhibiting low conductivity, an inherent characteristic of Lake Sammamish (Birch 1976). The system has an effective sampling range to a depth of 3.7 m, dependent upon water clarity and conductivity. Boat design originated from an unpublished Washington State Department of Game manuscript prepared by Bill Zook, Regional Fish Biologist, Ephrata Regional Office.

Sport fishing for bass on Lake Sammamish generally begins in April and extends through August, with peak effort occurring in May and June. Samples were secured by Coop Unit biologists or from organized bass tournaments conducted during the sampling seasons. The capture and release location was noted for each smallmouth and Floy Anchor Tags (Model FD-86) were attached to each fish greater than 20 cm in total length (TL). A total of 478 smallmouth bass was tagged and released during the 2-yr period, 187 in 1979, and 291 in 1980.

Smallmouth bass homing behavior was determined from 240 bass captured within one lake section and transported and released at another randomly selected lake section. Homing responses were categorized: (i) Specific Homing Response—relocated smallmouth bass that returned to the initial capture section from the randomly chosen release site; (ii) Sedentary Response—relocated smallmouth bass recaptured within the release section; and (iii) Mobile Response—relocated smallmouth bass that had moved outside the release section when capture took place. The smallmouth bass used in the homing phase of the study were relocated 0.8 to 11.3 km away from the point of initial capture.

Smallmouth bass movement behavior within a home range was determined from 238 bass captured, tagged, and released within the same lake section. The recapture data derived from these bass were used to determine the degree of

territorality elicited by smallmouth bass. Movement responses fell under two categories: (i) Sedentary Response—smallmouth bass that maintained a residence within the initial capture-release section; and (ii) Mobile Response—smallmouth bass that were recaptured outside of the initial capture-release section.

Homing behavior and home range movement patterns as defined by Gerking (1959) were monitored for smallmouth bass from March to September during 1979 and 1980 in Lake Sammamish. All recaptures were obtained by electrofishing and hook and line sampling. Any tagged bass recaptured within 5-d of release were not included in the analysis. These bass were defined as having inadequate time to elicit an accurate homing or movement response.

RESULTS

Of the 478 smallmouth bass tagged during the study (187 in 1979 and 291 in 1980), 69 were recovered, 19 between April and August of 1979 and 50 between May and August of 1980. However, nine of these recoveries were not used in the movement and homing portion of the study due to incomplete or inaccurate recovery data or because the recapture was made within 5-d of the release date. Two smallmouth bass were recaptured three times, while three were recaptured twice.

Thirty-three of the total smallmouth recoveries originated from the 240 that had been transported out of the initial capture section before release occurred. The other 27 recoveries were from 238 smallmouth bass that had been tagged and then released into the same lake section.

Of the 33 recovered smallmouth bass that had been released between 0.8 to 11.3 km away from the initial capture section, 41% returned back to their initial capture section before the recovery took place (Figure 1). These smallmouth displayed a direct homing response by returning specifically to their initial residence areas and by traveling as far as 9.7 km to return to the initial capture area. Many of these fish returned to the exact location, such as a dock, or other notable landmark, from which they had originally been captured.

Another 38% of the total recaptures responded by moving out of the offsite release section and into a new section of the lake, other than the initial capture section, when the recovery took place (Figure 1). Some of these smallmouth were possibly returning to the initial capture section when recovery occurred, because they were most often collected at sites located between the area of original capture and subsequent release. The remaining 21% of these relocated smallmouth were recaptured within the new section where they were released, indicating a sedentary response (Figure 1). All sedentary bass were recaptured within 6 to 10-d after the release date. Long-distance homing responses of smallmouth bass were observed to occur both across the lake in an east-west direction (Figure 2) and along the lake's length in a north-south direction (Figure 3). The smallmouth bass in Lake Sammamish returned to their home areas after release at random locations outside their original capture sites (Figure 2) and after release from a central weigh-in area following organized bass tournaments (Figure 3).

Twenty-seven smallmouth bass were recaptures of fish originally captured, tagged, and released within the same lake section. Six of these were recaptured during 1979 and the other 21 during 1980. Of these recaptured bass, 81% were recovered from the section of the lake where they were released, indicating a territorial response (Figure 4). The remaining 19% of the recaptures were recovered outside the capture and release section. The distances these bass moved ranged from 0.8 to 4.8 km from the original section of capture and release.

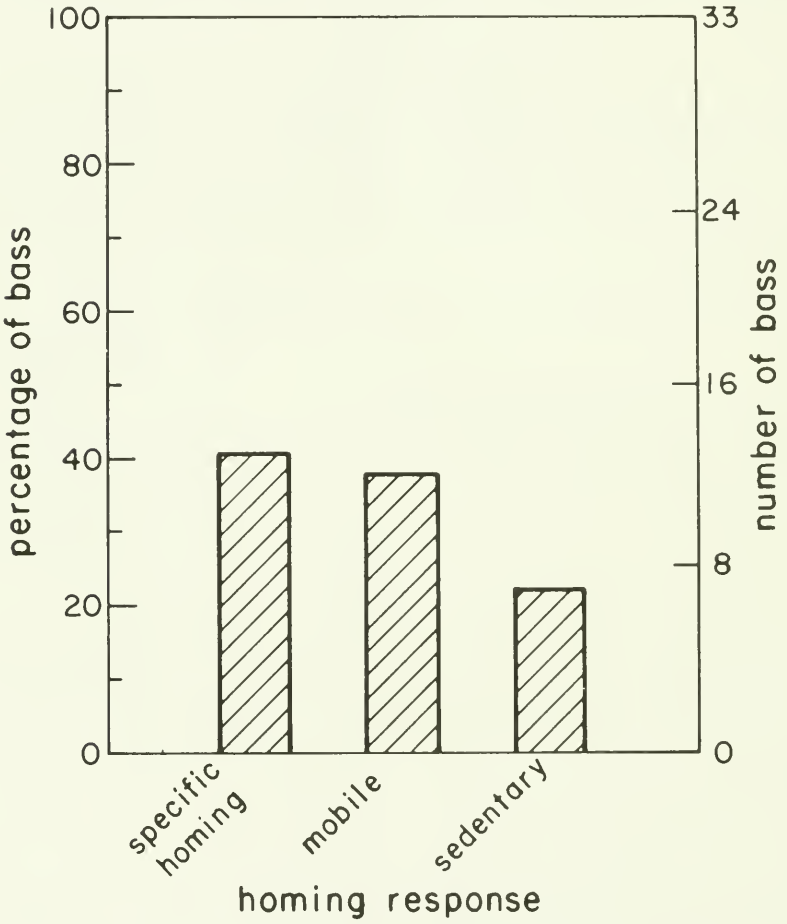

FIGURE 1. The homing responses from 33 recaptured smallmouth bass transplanted out of the initial capture section before release occurred.

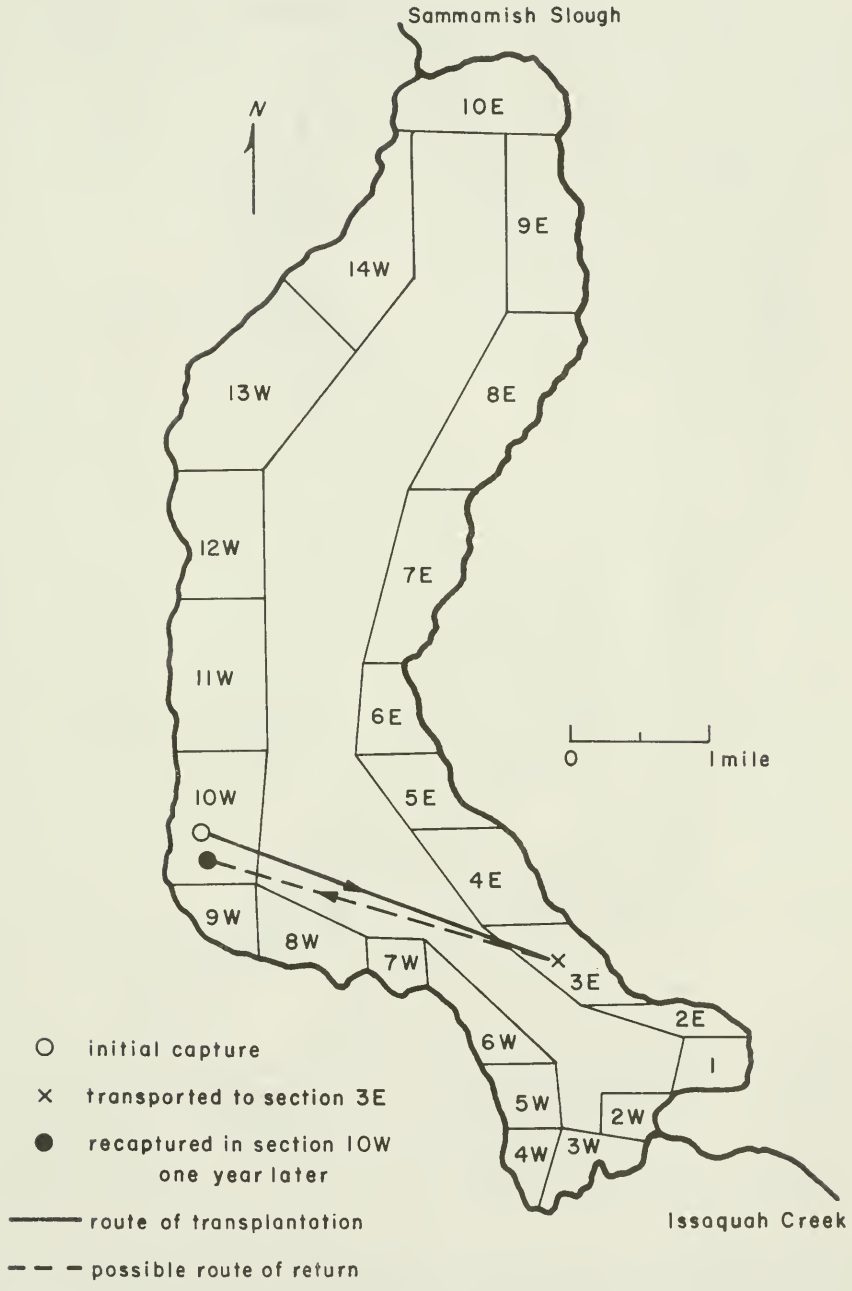

FIGURE 2. The direct homing response of a tagged smallmouth bass initially captured in Section 10W, released in Section 3E approximately 4.8 km away, and recaptured in Section 10W.

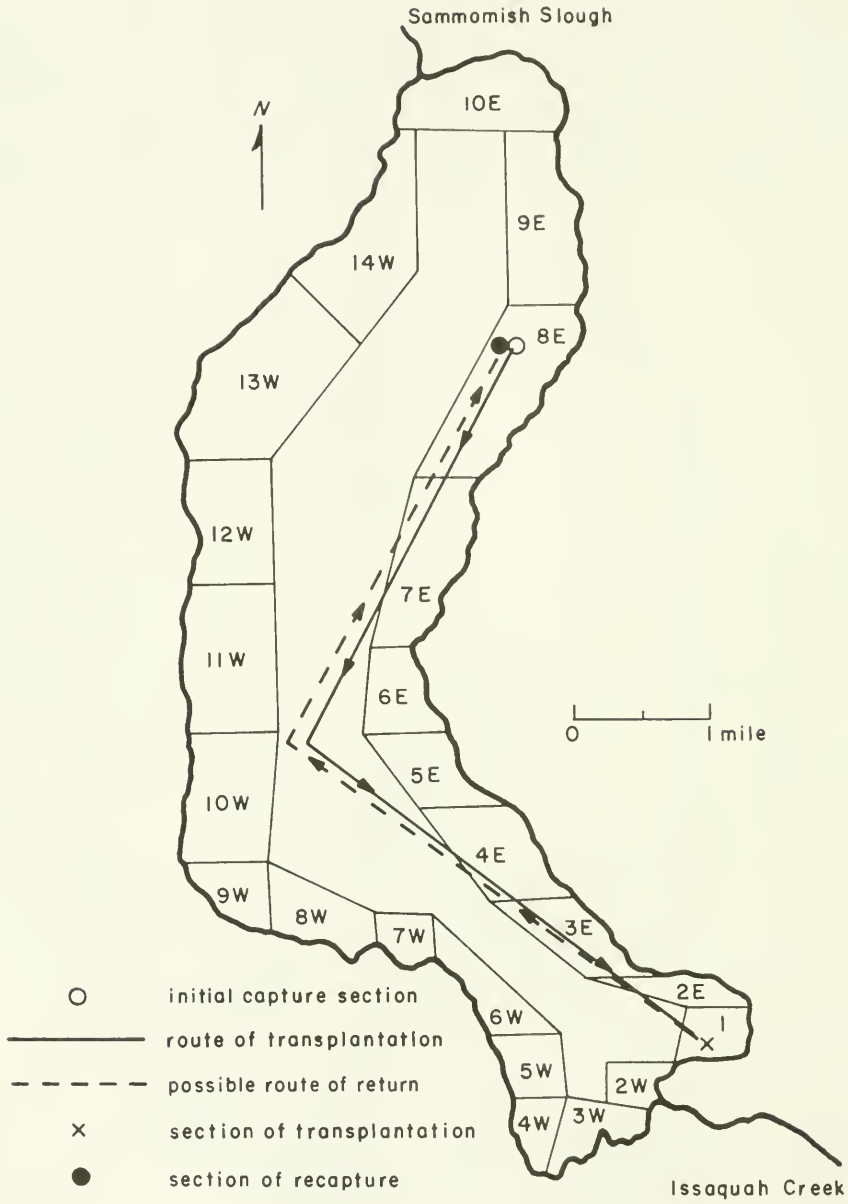

FIGURE 3. The direct homing response of a tagged smallmouth bass initially captured in Section 8E and released in Section 1, 11.3 km away, and recaptured in Section 8E.

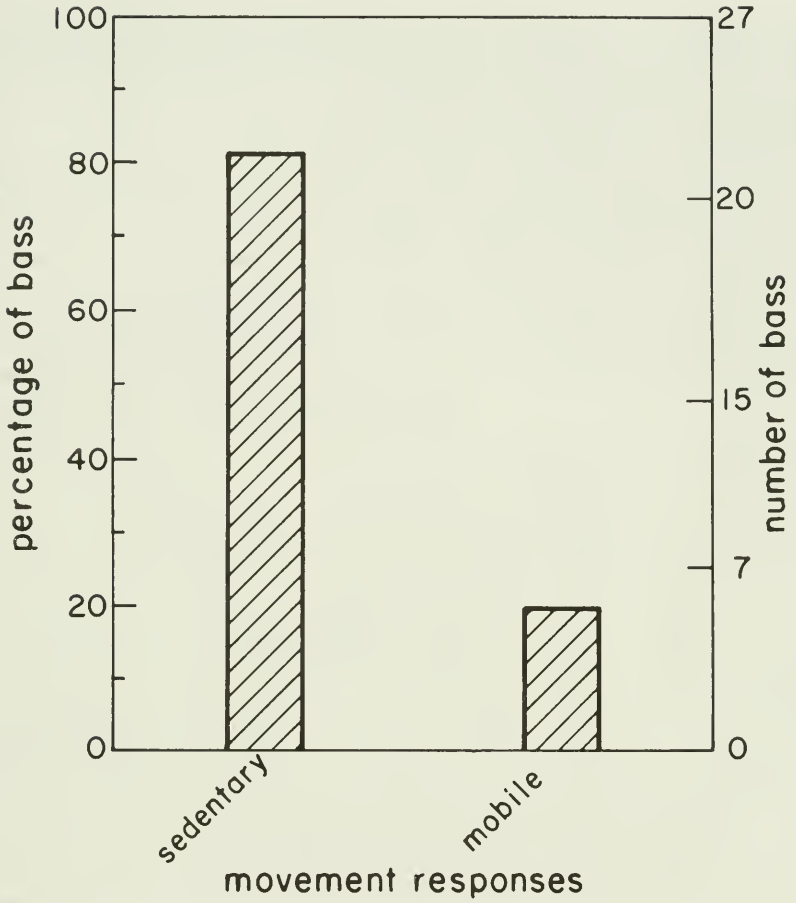

FIGURE 4. The responses of 27 recaptured smallmouth bass released after tagging within the same lake section as their initial capture.

DISCUSSION

Smallmouth bass recapture locations determined by electrofishing provided accurate information on the movement and homing of individual bass. Angler recapture data were also used to determine the movement and homing patterns of smallmouth bass, but only when the angler could identify the recapture site accurately. Angler accuracy was typically contingent upon familiarity with the lake or previous exposure to the recapture procedures of the study. The majority of the anglers were able to supply accurate accounts of recaptured smallmouth bass. Nineteen of the 187 smallmouth bass tagged and released within Lake Sammamish during the spring and summer of 1979 were recaptured before November of the same year. During the following spring and summer only one of the smallmouth tagged in 1979 appeared in the 1980 recaptures. Van Woert (1980) noted a high percentage of smallmouth bass tags were returned by anglers within a 3-yr period following tagging. Pelzman, Rapp, and Rawstron

(1980) have indicated a conscientious effort by anglers to return tags, noting that smaller fish with tags were retained that otherwise would have been released. In this study, Lake Sammamish anglers seemed very conscientious about getting information to us about tagged fish.

Lake Sammamish smallmouth that were captured, tagged, and released within the same lake section apparently remain within a distinct residence area, since 81% were recaptured inside the lake section of initial capture and release. The remaining 19% moved relatively short distances outside the initial capture section, usually less than 1.6 km. Fraser (1955) and Forney (1961) encountered similar findings in Lake Huron, Michigan, and Lake Oneida, New York respectively. In Lake Huron, 72% of the lake-dwelling smallmouth bass that were tagged and released back to the same area were recaptured within 3.2 km of the point of release (Fraser 1955), while in Lake Oneida, 80% of the bass tagged and released within the same area were recaptured by anglers within 2.4 km of the tagging site (Forney 1961). At Folsom Lake, California, Rawstron (1967) reported that seven recaptured smallmouth bass out of 23 originally tagged fish had moved an average of only 1.1 km from the point of tagging.

Smallmouth bass inhabiting rivers also appear to occupy distinct home areas (Paragamian and Coble 1975). Reynolds (1965) found tagged smallmouth bass in rivers moved very little from the site where they were tagged with maximum movement only 3.2 km away. Movement within streams by smallmouth bass is normally restricted to a limited section of water, usually one distinct pool, and any movement can be directly correlated with the physical stability of the stream substrate (Fajen 1962). Henderson and Foster (1956) noted that marked smallmouth bass returned to areas from which they were first captured, but felt a random wandering back into a preferred type of habitat was occurring rather than a definite homing instinct. Of all fish free at least 7-d, 99 (76%) of the recovered smallmouth were found in the same location in which they were tagged and released, while 22 of 31 fish recovered outside the pool in which they were marked had moved less than 1.6 km according to Munther (1970). Smallmouth in the Columbia River entered sloughs to spawn in Mid-March and remained there until August at which time they returned to the closest deep water habitat available, which can be a considerable distance from the spawning area (Montgomery and Fickeisen 1978, Montgomery *et al.* 1980).

Smallmouth bass in Lake Sammamish demonstrated the ability to return specifically to their original residence areas after displacement. Smallmouth bass captured within one lake section and released from 0.8 to 11.3 km away, showed a tendency to return to the original site. In fact, some of these recaptures were made precisely at specific landmarks where the initial capture had been made. This demonstrates the ability of the smallmouth bass to home back to the original residence area and perhaps recognize a precise niche (Gerking 1959). Another 38% of the displaced smallmouth bass had moved out of the release section and into new areas of the lake and were recaptured from areas that were in a position that logically appeared to be enroute to their original capture site. Therefore, it is suggested that many, if not all, of these smallmouth were moving back toward their original residence area when recapture occurred.

From our data and that of others (Fraser 1955, Forney 1961, Reynolds 1965, Munther 1970) it is apparent that smallmouth bass show a strong tendency to establish a home base or territory. Omand (1951) found that a drastic reduction

of the population in one area of a lake is not followed by migration into that area by smallmouth from outside the area. This tendency has strong management implications when either of two situations for expanding the fishery is considered. First, the expansion of existing fish stocks within a lake into other sections where they do not exist may be a difficult task to accomplish, even in a large lake or reservoir because of the tendency of smallmouth to return to their original site of residence. Second, if small numbers of adult smallmouth are transplanted from one body of water to another for the purpose of establishing a new fishery, it may take an extremely long time for the fishery to develop if the fish are planted only at one location. This of course assumes that the adult fish would establish residence at the location where they are first introduced into the lake and not move around much prior to establishing a home residence area. The assumption also is made that juvenile smallmouth bass resulting from adult introductions will imprint and establish a home area very quickly and therefore will not disperse throughout the environment.

Therefore, due to the strong tendency of smallmouth bass to establish a home area we recommend that expansion of an existing population be accomplished with smallmouth bass from a separate body of water. Also, because of the possibility that stocked smallmouth bass and their offspring could quickly establish a home area residence at the location of introduction, waters not containing any existing smallmouth bass should be considered for stocking at several different locations to obtain maximum dispersal of the fish.

The movement of smallmouth bass within their home lake may have important implications for managing bass tournaments. If approximately 80% of all smallmouth bass brought to a central weigh-in location and subsequently released at that site could be expected to move rapidly back to their original capture location (home area), then possibly it would not be important to require tournament officials to transport smallmouth bass to some central lake location for release. Blake (1981) indicates that smallmouth bass displaced by tournament anglers tend to move and disperse more from a central release point than smallmouth bass released at their capture location after trapnetting. It is possible that the angler caught and displaced fish in Blake's (1981) study were moving back toward their original home area, such as those tournament caught fish did that were released at a central weigh-in area on Lake Sammamish.

It appears that tournament caught smallmouth bass will disperse from a central weigh-in area. However, in addition to the number of smallmouth leaving a tournament weigh-in location, the amount of time it takes for this to occur should also be considered by fishery managers when evaluating whether or not to move fish from the weigh-in area to a central disperal location.

ACKNOWLEDGEMENTS

This work was supported under a Cooperative agreement between the U.S. Fish and Wildlife Service, the Washington State Department of Game, and the University of Washington.

LITERATURE CITED

Bennett, G.W. 1970. Management of lakes and ponds. Van Nostrand Reinhold Co., New York, N.Y. 375 p.

Birch, P.B. 1976. The relationships of sedimentation and nutrient cycling to the trophic status of four lakes in the Lake Washington drainage basin. Thesis, Univ. of Wash., Seattle, Wash., U.S.A. 199 p.

Blake, L.M. 1981. Movement of tournament-caught and released bass. N.Y. Fish Game J., 28(1):115–117.

Coble, D.W. 1975. Smallmouth bass. Pages 21–33 *in* H. Clepper, ed. Black Bass Biology and Management. Sport Fishing Institute, Washington, D.C.

Fajen, O.F. 1962. The influence of stream stability on homing behavior of two smallmouth bass populations. Amer. Fish. Soc., Trans., 91(4):346–349.

Forney, J.L. 1961. Growth, movements and survival of smallmouth bass (*Micropterus dolomieui*) in Oneida Lake, New York. N.Y. Fish Game J., 8(2):88-105.

_____. 1972. Biology and management of smallmouth bass in Oneida Lake, New York. N.Y. Fish Game J., 19(2):132–154.

Fraser, J.M. 1955. The smallmouth bass fishery of South Bay, Lake Huron. Can. Fish. Res. Bd., J., 12(1):147–177.

Gerking, S.D. 1959. The restricted movement of fish populations. Cambridge Philosophical Soc., Biol. Rev., 34(2):221–242.

Henderson, C., and R.F. Foster. 1956. Studies of smallmouth bass (*Micropterus dolomieui*) in the Columbia River near Richland, Washington. Amer. Fish. Soc., Trans., 86(1):112–127.

Montgomery, J.C., and D.H. Fickeisen. 1978. Spawning and movements of smallmouth bass (*Micropterus dolomieui*) in the mid-Columbia River. Battelle, Pacific Northwest Laboratory Report PNL-2785, 14 p., Richland, Washington, U.S.A.

Montgomery, J.C., D.H. Fickeisen, and C.D. Becker. 1980. Factors influencing smallmouth bass production in the Hanford area, Columbia River. Northwest Science, 54(4):296–305.

Munther, G.L. 1970. Movement and distribution of smallmouth bass in the middle Snake River. Amer. Fish. Soc., Trans., 99(1):44–53.

Omand, D.N. 1951. A study of populations of fish based on catch-effort statistics. J. Wildl. Manage. 15(1):88–98.

Paragamian, V.L., and D.W. Coble. 1975. Vital statistics of smallmouth bass in two Wisconsin rivers, and other waters. J. Wildl. Manage., 39(1):201–210.

Pelzman, R.J., S.A. Rapp, and R.R. Rawstron. 1980. Mortality and survival of tagged smallmouth bass, *Micropterus dolomieui*, at Merle Collins Reservoir, California. Calif. Fish Game, 66(1):35–39.

Pflug, D.E. 1981. Smallmouth bass (*Micropterus dolomieui*) of Lake Sammamish: A study of their age and growth, food and feeding habits, population size, movement and homing tendencies, and comparative interactions with largemouth bass. Thesis, Univ. of Wash., Seattle, Washington, U.S.A. 80 p.

Rawstron, R.R. 1967. Harvest, mortality, and movement of selected warmwater fishes in Folsom Lake, California. Calif. Fish Game, 53(1):40–48.

Reynolds, J.B. 1965. Life history of smallmouth bass, *Micropterus dolomieui* Lacepede, in the Des Moines River, Boone County, Iowa. Iowa State J. Sci., 39(4):417–436.

Schneberger, E. 1977. Smallmouth bass life history, ecology and management. Wis. Dept. Nat. Resour. Publ. No. 16-3600(77), 15 p., Madison, Wisconsin.

Van Woert, W.F. 1980. Exploitation, natural mortality, and survival of smallmouth bass and largemouth bass in Shasta Lake, California. Calif. Fish Game, 66(3):163–171.

Watson, J.E. 1965. The Maine smallmouth. Maine Dept. Inland Fish Game, Fish Res. Bull. No. 3, 31 p., Augusta, Maine.

Woodbury, E.D. 1975. Smallmouth bass (*Micropterus dolomieui*); an annotated and selected bibliography. U.S. Dept. Inter., Nat. Resour. Lib., Bibliography Series No. 32, 33 p., Washington, D.C.

Calif. Fish and Game 69(4): 217–226 1983

SPRING POPULATION TRENDS IN *PHOCA VITULINA RICHARDI* IN TWO CENTRAL CALIFORNIA COASTAL AREAS [1]

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Two areas separated by about 17 km with comparable numbers of harbor seals were surveyed in Spring 1980. Population trends in the two areas were significantly different with a decline at the San Mateo County sites. In contrast to this area which had a low pupping rate, nursery herds were observed at the two Santa Cruz County sites. A group composed almost exclusively of males was observed in San Mateo County. Since there is no indication of movement between the areas, these contrasting distributions are interpreted as resulting from differences in habitat characteristics and frequency of human encroachment.

INTRODUCTION

Harbor seals, *Phoca vitulina richardi* are ubiquitous inhabitants of the California coastal zone. Although considerable research has been conducted on harbor seals (Scheffer and Slipp 1944, Bigg 1973, Newby 1973, Knudtson 1977, Pitcher and Calkins 1979) their population dynamics during the reproductive season are not well understood. In particular, an integrated picture of male-male interactions and mating strategies has not been accomplished.

Haul-out patterns are determined by several factors including weather, tidal pattern, time of day, season, and human proximity. Seals are gregarious during haul-out and may spend as much as 50% of their time hauled-out (Newby 1973). Although seals do not appear to migrate, some seasonal movements associated with pupping have been reported (Scheffer and Slipp 1944, Bartholomew 1949, Brown and Mate 1979). Fisher (1952) and Newby (1973) reported the formation of nursery herds in the spring.

We have seen male-male aggressive encounters in the water at a nursery area, as have other workers (Bishop 1967). In addition, all male herds have been observed in the spring at Humboldt Bay, California (Knudtson 1977). These scattered findings suggest that the distribution of the sexes may be different during the reproductive period.

Although there is a seasonal cline in pupping along the California coast (Bigg and Fisher 1975), parturition is synchronized within populations. In our study area, pupping begins in mid-April and lasts 4–6 weeks. Soon after weaning when females are in estrus (Fisher 1952, Bishop 1967, Bigg 1969), aquatic copulation presumably occurs. Several authors have suggested that harbor seals mate near the bottom in shallow nearshore areas (Venables and Venables 1957, Bishop 1967). Recently, a detailed analysis of *Phoca largha* copulatory behavior in captivity has been reported (Beir and Wartzok 1979). With the exception of this treatment for *P. largha*, the relationship between mating strategy and population structure is largely unknown for *P. vitulina* and its close relatives.

[1] Accepted for publication August 1982.

Population counts also may be affected by human presence. The impact of humans is known to be an important factor in haul-out patterns of some harbor seal populations (Venables and Venables 1957, Paulbitski 1975). In addition, human intrustion may disrupt the mother-pup bond (Bonner 1972, Pitcher and Calkins 1979). The San Mateo County coastal area is subject to heavy recreational use.

In this study we surveyed two areas along the San Mateo and Santa Cruz County coastlines that had similar numbers of seals, and compared population composition changes and pupping rates. Our primary purpose was to assess population fluctuations in the 1980 reproductive season. With this information we evaluated the hypothesis that *P. vitulina* is polygynous in contrast to their monogamous relative, *P. largha*.

METHODS

Study areas were in adjacent counties. The San Mateo County area included four sites separated by 5 km or less: Pigeon Point, Pebble Beach, China Cove, and Pescadero. In Santa Cruz County the two sites surveyed were The Ladder and Waddell, which are 2.2 km apart (there are several other hauling grounds in Santa Cruz County including Soquel, Wilder Ranch, and Año Nuevo (Figure 1).

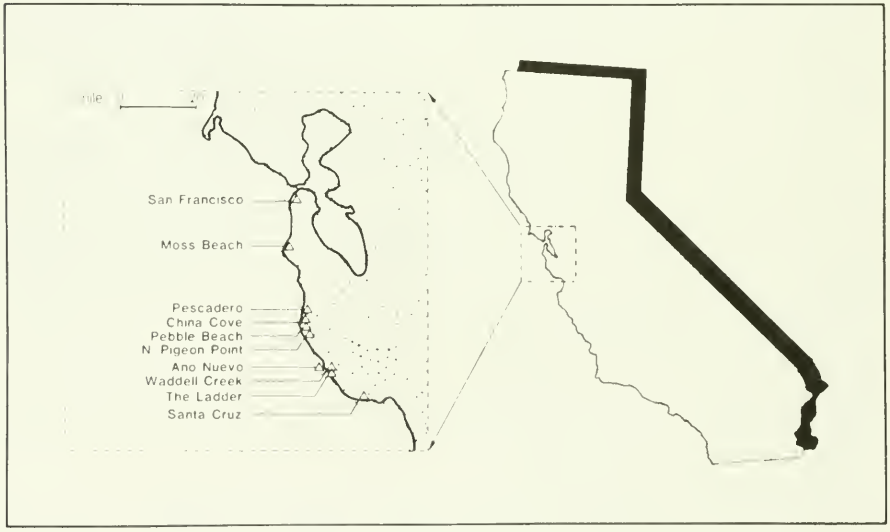

FIGURE 1. Study sites along the central California coast.

Criteria for grouping these sites into two areas included the facts that the two complexes were more than 16.6 km apart and that no interchange of individuals was observed between them. It is known that the seals haul-out on offshore rocks. While the Santa Cruz sites include rocks that are relatively level, with ample haul-out space and easy access to and from the water, the San Mateo sites all have more limited level areas and numerous irregular surfaces. Lastly, although both areas allow access by beachcombers during low tides, human traffic at the San Mateo sites is much heavier.

Counts were conducted at low tide 4 to 5 days a week using a Questar telescope, spotting scope and binoculars. A 35 mm SLR camera with 300-mm lens was used for photographic identification. The ability to sex and to repeatedly identify animals was essential. Animals were sexed by noting the penile opening in males and the paired abdominal teats in females. Ability to sex animals varied from site to site (maximum number reliably sexed was 78% at Waddell in June).

Card catalogs included descriptions of each seal's unique spot/scar pattern, with accompanying photographs where possible. Additionally, 16 seals at Waddell were marked with lanolin paint in blue, green, yellow, and red (Marine Mammal permit #290).

An individual was categorized as repeatedly identifiable if it was observed three or more times during the study. The ability to systematically reidentify individuals enabled us to note population composition changes and movements between areas. During the spring of 1980, 114 animals were repeatedly identifiable, 86 of which were at the Santa Cruz sites. Ability to reliably identify individuals at the Santa Cruz sites is a function of the irregular topography at the other sites and longer history of observation at Waddell. Despite the smaller number of identifiable seals, a number of cases of movement between San Mateo sites was observed.

RESULTS

For species like the harbor seal semimonthly maximums may better indicate use of an area than mean counts. Large fluctuations using mean data are revealed by the ranges represented in Table 1.

TABLE 1—Combined Censuses for the Santa Cruz Complex and the San Mateo Complex for Spring 1980.

	SAN MATEO								
	Total			*Adults*			*Subadults*		
DATE	$\bar{x}$	*Range*	*n*	$\bar{x}$	*Range*	*n*	$\bar{x}$	*Range*	*n*
Mar/Apr	76.8	36–100	12	59.8	27–76	12	14.7	5–23	12
May	44.5	17– 78	12	32.5	11–59	12	10.4	6–23	12
June	74.7	39–107	13	58.2	31–88	13	14.1	6–19	13
July	97.0	74–115	6	78.0	58–93	6	17.3	3–30	6
	SANTA CRUZ								
	Total			*Adults*			*Subadults*		
DATE	$\bar{x}$	*Range*	*n*	$\bar{x}$	*Range*	*n*	$\bar{x}$	*Range*	*n*
Mar/Apr	—No combined data—								
May	79.4	42–104	19	51.4	21–66	19	7.7	5–17	19
June	79.1	54–109	15	58.8	36–80	15	11.9	7–23	15
July	66.0	18–125	6	45.0	15–91	6	16.3	4–31	6

Counts

San Mateo maximum counts decreased from 83 adults in the second half of February to 50 in the second half of May (Figure 2). The largest decrease in numbers within the San Mateo sites occurred at Pebble Beach (Figure 3). This decrease occurred in April and May which corresponds to the pupping period. It is apparent in the June data for adults that Santa Cruz populations tend to diminish when the San Mateo populations peak and vice versa, with a return to maximum populations at both sites in July (Figure 2).

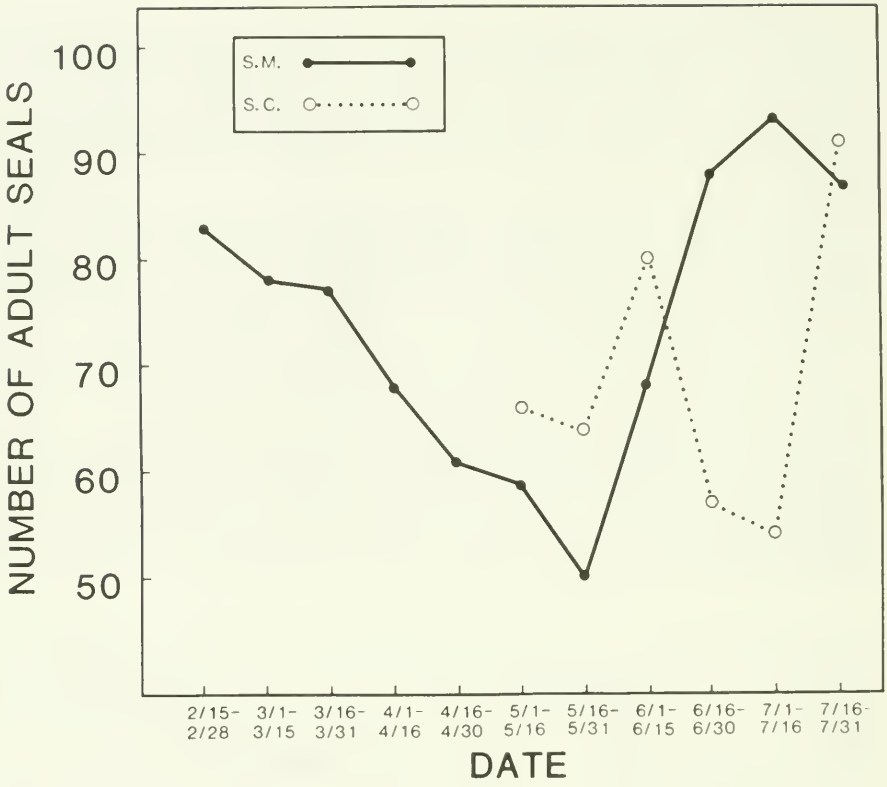

FIGURE 2. Semimonthly maximum censuses of adults at the San Mateo (S.M.) and Santa Cruz (S.C.) complexes.

There was a substantial decline in the mean number of animals at San Mateo in May and a marked increase in July (Table 1). There was no change in mean totals in May and June in Santa Cruz, but means declined slightly in July. This change occurred primarily in the adult component of the population (Table 1). Similar trends are apparent in maximum semimonthly counts (Figure 2). The mean numbers of adults stayed constant in May and June, dropping in July at Santa Cruz. A slightly different picture emerges when looking at semimonthly maximum numbers. There was a decline in maximum numbers of adults in the second half of June, with an increase in late July.

The number of subadults did not change dramatically during the study period. Mean numbers declined slightly at San Mateo in May then increased in June. At Santa Cruz there was a continual increase from May to July.

Numbers of seals peaked at Waddell in May and declined through July (Figure 4). The Ladder was not censused prior to May. Numbers at The Ladder peaked in the second half of July, when Waddell was at its lowest.

Numbers of seals at Pebble Beach declined in March, and stayed low through the end of May, then rapidly increased in June. A maximum of 98 seals was counted in July. The remaining sites all had similar counts (approximately 20–25 seals) until the end of May, when maximum counts increased at Pescadero and decreased at China Cove and Pigeon Point. This trend continued through June, but in July Pescadero numbers declined.

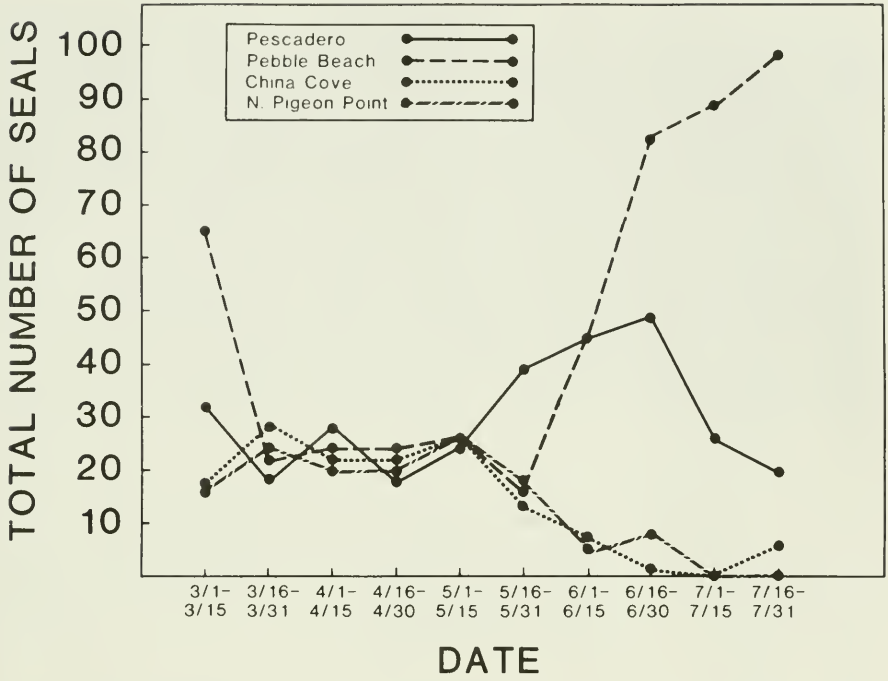

FIGURE 3. Semimonthly maximum censuses of the total number of seals hauled-out at the four San Mateo sites.

Sex Ratio

A change in the adult sex ratio was observed in April and May. For this period, both the Waddell and The Ladder sites were nursery areas populated primarily by females and pups (Figure 5). In contrast, China Cove, in the San Mateo complex, appeared to be inhabited predominantly by males from April through June. Of those animals sexed at The Ladder in May, there were more than seven times as many females as males. In June, the sex ratio showed a reduced preponderance of females. Correspondingly, at Waddell in May, females predominated by nearly three to one. In June, a similar proportion of the adult population was sexed and numbers of males and females were more nearly equal than in the previous period. At China Cove, we saw a different trend. In April, 35 males and 8 females were sexed. In May and June, no females were observed to haul-out there and seal numbers generally dropped to low levels (Figure 3). Smaller population size and low percentage sexed make conclusions drawn from China Cove data more tenuous than for other sites.

Site Fidelity

The observation that most harbor seals are site specific with only local movement (Pitcher and Calkins 1979, Brown and Mate 1979) is supported by our observations of known individuals (there are occasional exceptions, e.g., in Pitcher and Calkins, 1979, radio-tagged seals were seen to move maximum

distances of 128 km). For example, one large male at Pescadero was observed on the same spot on the same rock on 10 different days. Many individuals were seen on a daily basis during April and May at Waddell, while others were seen only sporadically. We do not know if this was an artifact of our ability to identify individuals or if some animals used multiple haul-out sites while others used one exclusively. Movement between nearby sites was observed commonly. It appeared probable that some seals used alternate sites when conditions were undesirable (heavy surf, human disturbance). This was the case in both areas, i.e., if there were fishermen at one site and no seals there, we often saw an atypically large group size at a nearby site. All age classes, including pups, were observed moving within each complex of sites. We observed intersite movement of identifiable seals 61 times (24 individuals) within the Santa Cruz sites and 28 times (7 individuals) within the four San Mateo sites. However, it is possible that movement between our study sites in either county and Año Nuevo may occur.

FIGURE 4. Semimonthly maximum censuses of the total number of seals hauled-out at the two Santa Cruz sites.

Pupping

In both areas, pups first were observed in mid-April. The first weaned pups were seen at both Santa Cruz sites on 23 May, which was approximately 5 weeks after the first pups were observed. This agrees with previous studies which state the suckling period lasts approximately 4–6 weeks (Bishop 1967, Newby 1973, Knudtson 1977). In the San Mateo area a lone pup was seen slightly earlier than in the Santa Cruz sites (11 May, at Pebble Beach). Before 1 June, maximum numbers of pups on any one day were 22 at Waddell and 14 at The Ladder with only scattered pups seen at Pigeon Point and Pebble Beach. On one occasion a single pup was sighted at China Cove indicating again that female-pup pairs may move. On the basis of preliminary studies conducted in 1978 and 1979, it was established that the mean weaning date at Waddell was 31 May. In 1980, maximum numbers of pups decreased after 1 June, as weanings occurred, presumably due to emigration and mortality. On a single day in June, eight weaned pups were observed at Pebble Beach, although only three female-pup pairs had ever been observed there previously. This movement of pups from the nurturing site is similar to that reported by Boulva (1975). The percent of pups in the population was lower in the San Mateo area than in the Santa Cruz area. It also was lower than in other populations that have been studied (Bishop 1967–32.2%; Bigg 1969–26.00%; Boulva 1976–25.7%). This may have been a function of the previously described rough topography and more frequent disturbance by humans.

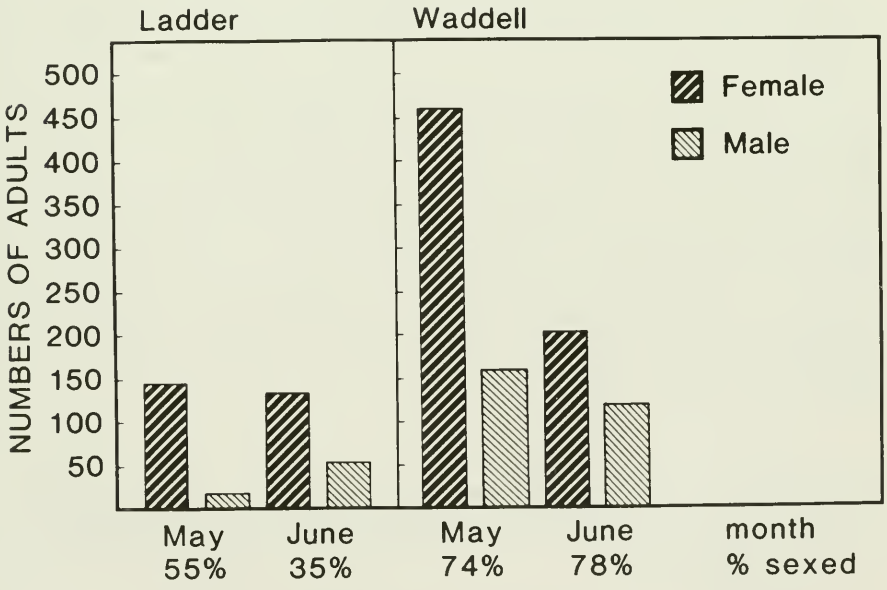

FIGURE 5. Total number of adults sexed at the Santa Cruz sites in May and June 1980.

During May there was a decrease in adults hauling-out at the San Mateo sites (Figure 1). Correspondingly, the pupping rate at San Mateo was depressed as compared with Santa Cruz and with the pupping rates in other harbor seal populations which have been studied (Bishop 1967, Bigg 1969, Boulva 1976). However, the pupping rates are difficult to compare with other studies because of the variety of methods used. Boulva (1976), working in eastern Canada, calculated birth rate as the percent of parturient females with respect to the preparturition population, Bishop (1967) in Alaska estimated birth rate as the percent of parturient females in the population on the basis of one census, and Bigg (1969) in Washington calculated the birth rate as the percentage of pups in the population at the close of the whelping season. We counted and compared total number of pups with respect to the total number of adults and subadults for all sites in both areas for 8 days in May. The percent of pups at San Mateo ranged from 0% to 11.8% for the 8 days censused. At the Santa Cruz sites, the percent of pups was much larger; ranging from 20.3% to 41.3%. We considered this method of comparison to be a more realistic indication of the pupping rate, because the total number of seals hauled-out on any given day in our study area fluctuated greatly (Table 1). The percent of females with pups in the Santa Cruz complex was similar to that reported in the literature for other populations of harbor seals (Bishop 1967, Bigg 1969, Boulva 1976). In contrast, the number of mother-pup pairs observed at San Mateo was low.

DISCUSSION

P. vitulina is an ubiquitous and successful species in widely varying habitats and our studies combined with others lend substance to the hypothesis that a significant part of this adaptiveness lies in the ability to dynamically change social structures.

Nursery herds were observed at the two Santa Cruz sites, while only scattered female-pup pairs were observed in San Mateo County. The two Santa Cruz sites were primarily populated by females during the pupping period. We found that one site, China Cove, had a population composed largely of males throughout the study period, with no females identified at this site in May and June. One plausible interpretation of the above findings is that male competition includes the active exclusion of other males from areas where females aggregate. This evidence combined with several elements of the literature on harbor seals and our findings of disproportionately large numbers of females at the Santa Cruz sites in May and June suggests that these seals are somewhat polygynous. The supporting evidence follows:

1. There are previously reported congregations of nursery herds (Fisher 1952, Newby 1973).
2. Where females are congregated, males are observed to fight and display increasingly as the season progresses. Superficial cuts on the neck, flippers, and head are observed commonly during this time (Bishop 1967, Slater unpublished data).
3. Knudtson (1977) has reported areas where males consistently predominate (similar to the findings we have reported).
4. There is slight sexual dimorphism, with the males larger (Bigg, 1969). Males mature later than females and males have a higher mortality (Bishop 1967, Bigg 1969, Pitcher and Calkins 1979).
5. All of these have been suggested as indicators of polygyny in mammals.

Confirmation of polygynous mating systems in some harbor seals would not be surprising, nor necessarily contradictory to earlier suggestions that some harbor seals are monogamous. For example, the grey seal may be monogamous or polygynous depending upon space restrictions (Mansfield 1966, Curry-Lindahl 1970). How much females clump varies in different areas. Whether clumping of females is a function of available hauling sites or a combination of other factors needs to be examined. The San Mateo sites may be more restrictive or otherwise less suitable than the sites in the Santa Cruz complex and topography may be important in haul-out patterns. The observation of scattered female-pup pairs at San Mateo vs. clumped pairs in Santa Cruz is an empirical fact. The probable cause of this difference remains uncertain, but the San Mateo sites are more surf-swept and have fewer sheltered pools and channels for pups to safely move in and out of the water. Besides influences of topography it is possible that females are clumping in response to predation pressure or differential feeding opportunities. Whatever the cause, it is clear that aggregation patterns may influence the shaping of social systems.

Human impact is known to have detrimental effects on the mother-pup bond in phocids (Fogden 1971, Stirling 1975). For example, several workers have suggested that human disturbance contributes to neonatal mortality by causing mother-pup separation (Bishop 1967, Boulva 1971, Bonner 1972). It seems likely that there is a relationship between depressed pupping and human disturbance in this study as well. There are two plausible explanations for the temporary decrease in population size at San Mateo and correspondingly low pupping rate. The first possibility is that adults are spending a larger proportion of their time in the water. This might be a function of the heavier pressures from human traffic. We have observed that human encroachment causes large numbers of seals to move into the water. Although we did not undertake a systematic study of human disturbance, it appeared that this was a critical factor in San Mateo hauling patterns. Alternatively, it is conceivable that adults are moving elsewhere to pup. We do not know of any local pupping areas north of Pescadero. Southward, there are nursery areas at Año Nuevo Island and at the two Santa Cruz sites. We have no records of individuals moving from San Mateo to Santa Cruz, although this does not preclude the possibility that movement is occurring. It does not seem likely that a large number of females are moving to Año Nuevo Island to pup because census trends there are similar to those at our San Mateo sites with numbers decreasing in May and peaking in July (LeBoeuf and Bonnell 1980). Further, Orr and Poulter (1965) reported that harbor seals on Año Nuevo island were not migratory, with only limited movement back and forth from Año Nuevo Point.

In summary, we have seen a seasonal shift in sex ratio and population composition in harbor seals at two coastal areas. An important element of these shifts was the formation of nursery herds and a male herd. We have seen that topography and human encroachment may modify observable population distribution patterns.

ACKNOWLEDGMENTS

We wish to thank B. LeBoeuf for his continuous support and advice and the owners of Big Creek Lumber Company, H. and F. McCrary, for their generous assistance.

LITERATURE CITED

Bartholomew, G. A. 1949. A census of harbor seals in San Francisco Bay. J. Mam., 30: 34–35.

Beir, J. C. and D. Wartzok. 1979. Mating behavior of captive spotted seals (*Phoca largha*). Anim. Behav., 27: 772–781.

Bigg, M. A. 1969. Clines in the pupping season of the harbor seal, *Phoca vitulina*. Bull. Fish. Res. Bd. Canada, 26: 449–455.

_____ 1973. Adaptations in the breeding of the harbor seal, *Phoca vitulina*. Reprod. Fert., 19 (Suppl.): 131–142.

Bigg, M. A. and H. D. Fisher. 1975. Effect of photoperiod on annual reproduction in female harbor seals. Rapp. P-V Reun. Cons. Int. Explor. Mer., 1969: 141–144.

Bishop, R. H. 1967. Reproduction, age determination and behavior of the harbor seal, *Phoca vitulina L.*, in the Gulf of Alaska. Thesis, University of Alaska, Fairbanks, 121 pp.

Bonner, W. N. 1972. The grey seal and common seal in European waters. Oceanogr. Mar. Biol. Annu. Rev., 10: 461–507.

Boulva, J. 1969. Observations on a colony of whelping harbor seals, *Phoca vitulina concolor*, on Sable Island, Nova Scotia. Can. Fish. Res. Bd. J., 28: 755–759.

_____ 1976. *Phoca vitulina concolor*. Advis. Comm. Mar. Res. Res. Scientific Consultation on Mammals. Bergen, Norway. Food & Agriculture Organization of the United Nations. 1–6.

Brown, R. and B. Mate. 1979. Movement of tagged harbor seals, *Phoca vitulina*, between two adjacent Oregon estuaries (Netarts and Tillamook Bays). Paper read at the Third Conference on the Biology of Marine Mammals, Seattle, Washington.

Curry-Lindahl, K. 1970. Breeding biology of the Baltic grey seal, *Halichoerus grypus*. Zool. Gard., 38: 16–29.

Fisher, H. D. 1952. Breeding biology of the harbor seal in British Columbia with particular reference to the Skeena River. Bull. Fish. Res. Bd. Canada, 1972: 1–33.

Fogden, S. C. 1971. Mother-young behavior at gray seal breeding beaches. J. Zool. (London), 164: 61–92.

Knudtson, P. M. 1977. Observations on the breeding behavior of the harbor seal in Humboldt Bay, California. Calif. Fish and Game, 63: 66–70.

LeBoeuf, B. J. and M. L. Bonnell. 1980. Pinnipeds of the California islands; abundance and distribution. Pages 475–493, *in* P. M. Power, ed. The California islands: proceedings of a multidisciplinary symposium Haagan Printing, Santa Barbara.

Mansfield, A. W. 1966. The grey seal in eastern Canadian waters. Can. Audubon, 28: 161–166.

Newby, T. C. 1973. Observations on the breeding behavior of the harbour seal in the State of Washington. J. Mam., 54: 540–543.

Orr, R. T. and T. C. Poulter. 1965. The pinniped population of Año Nuevo Island, California. Proc. Cal. Acad. Sci., 32: 377–404.

Paulbitsky, P. A. 1975. The seals of Strawberry Spit. Pacific Discovery, 28: 12–15.

Pitcher, K. and D. Calkins. 1979. Biology of the harbor seal, *Phoca vitulina richardsi*, in the Gulf of Alaska. U.S. National Oceanic and Atmospheric Administration. Environmental assessment of the Alaska shelf. Vol. 1: 189–225.

Scheffer, V. B. and J. W. Slipp. 1944. The harbour seal in Washington State. Am. Mid. Nat., 32: 373–416.

Stirling, I. 1975. Adoptive suckling in pinnipeds. Australian Mam., 1: 389–391.

Venables, U. M. and L. S. V. Venables. 1957. Mating behavior of the seal *Phoca vitulina* in Shetland. Proc. Zool. Soc. Lond., 128: 378–396.

Calif. Fish and Game 69(4): 227–242 1983

GROWTH, MATURITY, AND FECUNDITY OF THE CRAYFISH, *PACIFASTACUS LENIUSCULUS,* FROM THE SACRAMENTO-SAN JOAQUIN DELTA [1]

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The growth rate, age and size at maturity, and fecundity of *Pacifastacus leniusculus* in the Sacramento-San Joaquin Delta were studied between 1975–1979. The growth curve was linear over the size range observed, with no significant difference between males and females. Males, however, became significantly heavier than females with increasing length. The mean increase in length per molt was 6.6 mm, with three identifiable molting periods between spring and fall. The smallest sexually mature individuals observed were a 64 mm TL female (age 0+) and a 60 mm TL male (age 0+). By age 4+ (>112 mm TL), all crayfish examined were sexually mature. The percentage of mature individuals varied significantly, both by size class and age class, among the years sampled. Older, larger females carried significantly more eggs than smaller, younger females. The number of eggs per millimetre of length also varied among the years sampled. Pleopod egg counts ranged from 62 to 82% of the mean ovarian egg complement. Crayfish exhibit great variability in many of their life history parameters reflecting their adaptability to changes in environmental conditions. More study is needed on both wild populations in diverse habitats and populations held under controlled, experimental conditions.

INTRODUCTION

The growth rate, age and size at maturity, and fecundity of the crayfish, *Pacifastacus leniusculus leniusculus* in the Sacramento-San Joaquin Delta were studied between 1975–1979. Data describing these life history parameters were gathered as part of a study to assess the status of the Delta crayfish population and the commercial fishery it supports (Osborne 1977, 1978; McGriff 1983).

Previous studies on populations of *P. leniusculus* in Oregon, Washington, Lake Tahoe in California and Nevada, British Columbia, and Sweden demonstrated great variability in growth, maturity, and fecundity among different populations (Miller 1960; Mason 1963, 1975, 1977; Abrahamsson and Goldman 1970; Abrahamsson 1971; Brink 1975; Flint 1975). My results were important in establishing a management plan for the Delta population and in adding to the body of knowledge on wild populations of *P. leniusculus.*

THE DELTA REGION

The Sacramento-San Joaquin Delta is formed by the confluence of the south-flowing Sacramento River and the north-flowing San Joaquin River in the Central Valley of California (Figure 1). This area was once a vast tidal marsh, but levee construction in the 19th century transformed it into a network of navigable channels enclosing agricultural islands.

[1] Accepted for publication September 1982.

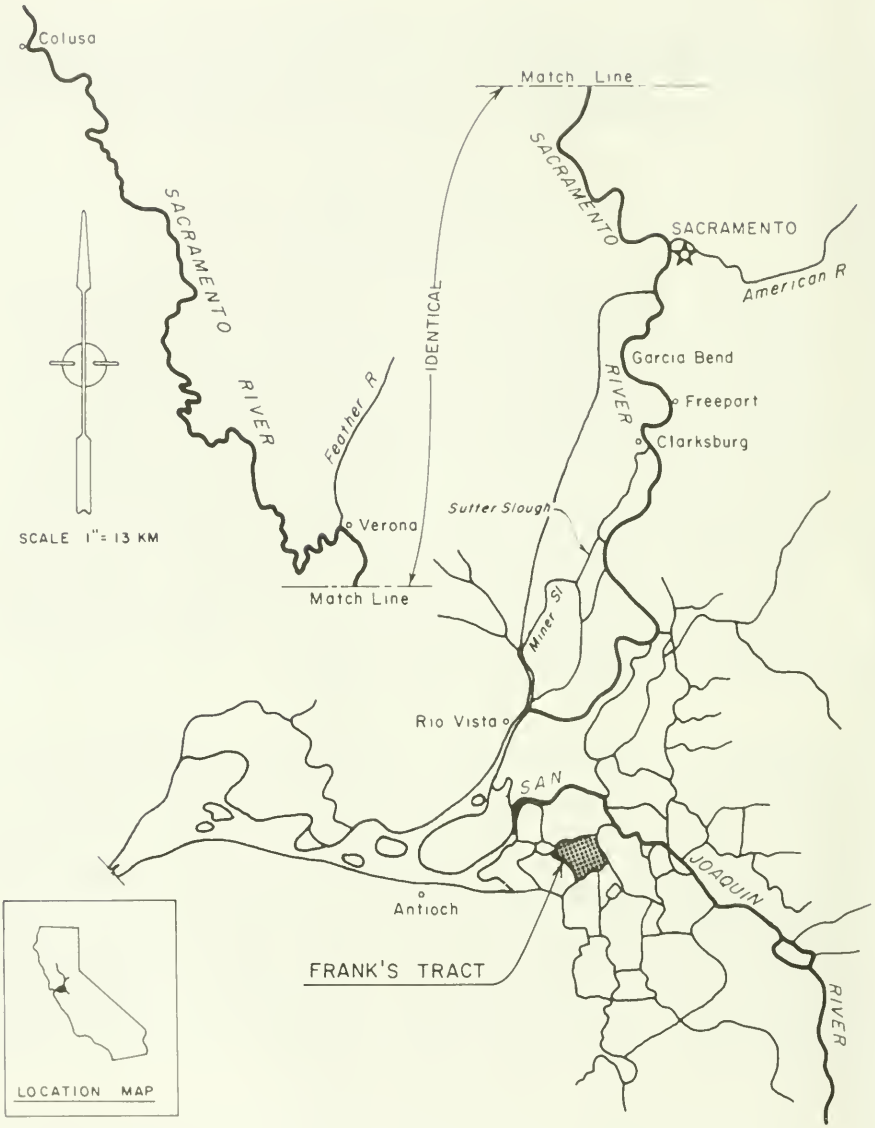


FIGURE 1. Map of the Sacramento-San Joaquin Delta and the Lower Sacramento River.

The Delta region is a complex and diverse environment, influenced by semidiurnal tides that reverse flows as far up river as Clarksburg (69 river km), and alter water levels and velocities as far north as Verona (129 river km). Rising tides also carry sea water into the Delta region. The extent of this saltwater intrusion depends on the magnitude of freshwater releases from upstream dams and varies annually and seasonally. The Delta waterways vary in width from nearly 1 km in the lower Sacramento River at Rio Vista, to less than 0.1 km in some

interior sloughs. Depths vary from about 16 m in parts of the San Joaquin River to less than 3 m in some interior sloughs. The waters in the Delta region are well mixed at all times of the year by wind and tidal currents and show little or no vertical stratification (Kelly 1966). Water temperatures throughout the region are fairly uniform and range from a mean summer temperature of 21.5°C to a mean winter temperature of 9.2°C. Dissolved oxygen levels have an annual mean of 9.2 mg/l (range = 5.0 mg/l to 12.4 mg/l), but vary seasonally with water temperature (Calif. Dep. Water Resources 1962, 1977, 1978, 1979; U. S. Dep. Interior 1972, 1973, 1974). The bottom composition of the rivers and sloughs is influenced by the currents but is generally some combination of sand, silt, and clay with everchanging configurations of submerged snags and other debris. Many levee banks in the Delta have been stripped of riparian vegetation and lined with rip-rap to prevent erosion.

MATERIALS AND METHODS

Growth

Estimates of crayfish growth, measured as the increase in length per molt, were obtained from a mark-recapture study carried out in Sutter and Miner sloughs (Figure 1). All crayfish were measured to the nearest millimetre total length (TL) from the tip of the acumen to the end of the telson. All lengths given are in mm TL. Using a modification of Abrahamsson's (1965) cauterization technique, I marked 3,310 crayfish between 49 and 141 mm between April and October 1976. A binomial code was used to mark crayfish in 3-mm size groups. The crayfish were marked in the laboratory and within 24 hours were returned to the capture site. Recaptured crayfish that had molted were measured and removed from the sampling area to insure that they were not sampled again.

Attempts to collect young-of-the-year crayfish were ineffectual. Small (6×6 mm) mesh minnow traps set on the rip-rap in about 0.3 m of water were unsuccessful, as were attempts to move rocks and dip net juveniles at the water's edge.

The length-weight relationship between sexes was determined from 100 females between 49 and 126 mm and 104 males between 57 and 131 mm taken from the Sacramento River. Crayfish were selected randomly from trap catches, measured, and weighed to the nearest 0.5 g on a Mettler P 160 N balance. The relationship was tested by analysis of covariance.

Information on molt frequency was obtained by noting the incidence of newly molted individuals in trap catches throughout the year and by dissecting samples of crayfish through the year to measure the size of the gastroliths (Shimizu and Goldman 1983).

Age Composition

Age class boundaries from Delta crayfish were set using Cassie's (1954) probability paper method of separating polymodal length-frequency data into its component groups or ages. The analysis was run on commercial catch samples from July 1975 (1,244 crayfish) and the entire 1976 season (5,160 crayfish) (McGriff 1983).

Maturity

For maturity studies, 458 females between 49 and 131 mm and 381 males between 53 and 127 mm were collected with baited traps in the Sacramento

River between Sacramento and Freeport (Figure 1), during the 6-wk period from mid-September through October of 1977–1979. Females were considered mature if the ovaries contained well-developed eggs. Males were considered mature if the vas deferens was thickened and contained sperm. The percentage of mature individuals was calculated for each sex, each year for age classes 1+ to 4+, and for each 5-mm size class from 70–74 mm to 110 mm and larger.

Fecundity

Fecundity was determined by counting either ovarian or pleopodal eggs. Ovarian eggs were counted from a sample of 50 mature females between 72 and 128 mm taken in 1979 from the Sacramento River. Whole crayfish were boiled to harden the eggs and the ovaries were removed. Mature eggs were then easily separated from each other by gently rolling them between the fingers. All mature eggs from each crayfish were counted.

Pleopodal egg counts were made on 324 berried females between 70 and 132 mm collected between October and December in 1975, 1977, and 1978. Eggs were stripped from the pleopods with forceps and counted. The mean number of pleopod eggs for ages 2+ and 3 and older crayfish was calculated for each year. The number of pleopod eggs per millimetre of length of the female was calculated for all crayfish for all 3 years so comparisons could be made among the years sampled.

RESULTS

Growth

A total of 456 marked crayfish that had molted were recaptured between July and October 1976. Of these, three appeared to have molted more than once. Regression analysis of premolt versus postmolt lengths of the remaining 453 showed a linear growth function over the size range observed (64 to 117 mm) (Figure 2), with no significant difference between males and females (t-test, $P > 0.05$). The grand mean increase per molt of 6.6 mm was fairly constant over the size range examined (Table 1).

Total annual growth is the product of length increase at molting and molt frequency. In the Delta, three molting periods occurred between spring and fall for crayfish ≥ 64 mm. The first occurred between the end of March and the end of April, at the end of the winter dormant period. Almost all crayfish molted at this time. Observations indicated juveniles and males molted first, with adult females molting after the newly-hatched young take up independent existence. Shimizu and Goldman (1983) documented a second molting period that extended from about the middle of May to the middle of June. It was less obvious in trap catches than the other two molting periods, since primarily only crayfish < 92 mm TL (the minimum legal commercial length) molted. The third molting period extended from about mid-August until mid-September. All but the largest individuals molted at this time and trap catches were reduced.

Males became significantly heavier than females with increasing length (analysis of covariance $P < 0.05$). The regression equations obtained are:

Males: $\text{Log W (g)} = -4.85217 + 3.18725 \text{ Log L (mm)}$, $r = 0.99$

Females: $\text{Log W (g)} = -4.62492 + 3.05682 \text{ Log L (mm)}$, $r = 0.99$

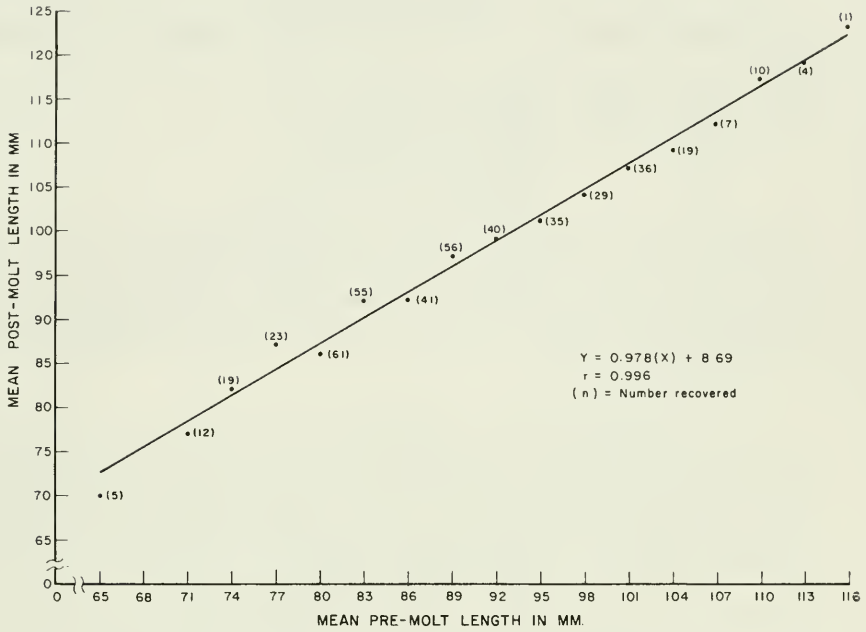


FIGURE 2. Growth of Delta Crayfish as indicated by the relationship between mean pre-molt and mean post-molt lengths.

TABLE 1. Mean Length Increase (mm) Per Molt of Marked Delta Crayfish

Length interval	*Number recaptured*	*Mean length at recapture*	*Mean length increase*	*Mean percent increase*
61– 63	1	81.0*	19.0*	30.6*
64– 66	5	69.8	4.8	7.4
67– 69	2	83.5*	15.5*	22.8*
70– 72	12	76.8	5.8	8.2
73– 75	19	81.7	7.7	10.4
76– 78	23	86.6	9.6	12.5
79– 81	61	86.4	6.4	8.0
82– 84	55	91.6	8.6	10.4
85– 87	41	91.7	5.7	6.6
88– 90	56	96.7	7.7	8.7
91– 93	40	99.3	7.3	7.9
94– 96	35	101.1	6.1	6.4
97– 99	29	104.1	6.1	6.2
100–102	36	107.0	6.0	5.9
103–105	19	109.4	5.4	5.2
106–108	7	112.1	5.1	4.8
109–111	10	117.1	7.1	6.5
112–114	4	118.8	5.8	5.1
115–117	1	123.0	7.0	6.0
		Unweighted grand mean	= 6.6	

* Multiple molts assumed. Data not used in calculating grand mean.

Age Composition

Seven age classes were postulated for the Delta population and boundaries set at:

Age 0+ = ≤64 mm
Age 1+ = 65–78 mm
Age 2+ = 79–98 mm
Age 3+ = 99–112 mm
Ages 4+ – 6+ = ≥113 mm

The differences in age class cutoff points between the 1975 and 1976 samples in the Cassie analyses ranged from 2 mm for the younger age classes, to a maximum of 6 mm for the older age classes. Because of this increasing overlap in the boundaries for ages 5+ and 6+, ages 4+ to 6+ were grouped together as "older age classes."

Maturity

The smallest sexually mature individuals observed were a 64-mm female and a 60-mm male. These sizes corresponded to the 0+ age class. By age 4+ (> 112 mm), all individuals examined were mature. However, the percentage of mature individuals in age classes 1+ to 3+ and size classes between 70 and 131 mm varied from year to year (Figure 3, Table 2). The variability was particularly great for females. For example, the percentage of mature 2+ females ranged from 80.2% in 1977 to 36.8% in 1979, and the percentage of mature females in the 85 to 89 mm size class ranged from 82.0% in 1977 to 29.0% in 1979.

The fractions of mature individuals for ages 1+, 2+, and 3+ from 1977–1979 were treated as independent samples and Chi-squares were computed to test for the equality of the proportions. Significant differences were found among the years sampled ($X^2 = 9.21$, d.f. = 2, $P < 0.01$) for age 2+ and 3+ females, and age 2+ males (Figure 4). Since sample size contributes to the Chi-square value, larger samples of age 1+ individuals probably would have also shown statistically significant differences.

Fecundity

The mean number of pleopod eggs per female for age 2+ (79 to 98 mm) and age 3 and above (>98 mm) crayfish was calculated for 1975, 1977, and 1978 (Table 3). The mean number of eggs per age 2+ female was significantly less than the number for females age 3 and above, with the older and larger crayfish consistently carrying more eggs (2-way ANOVA, $P \leq 0.01$). A difference also was found among the years sampled in both mean number of eggs per age 2+ female and age 3 and above female, and in mean number of eggs per millimetre of length of all females, with significantly lower numbers of eggs produced in 1977 than in either 1975 or 1978 (2-way ANOVA, $P < 0.01$) (t-test, 1 tail, $P < 0.01$).

The mean number of ovarian eggs per female between 80 and 90 mm was compared for crayfish from the Delta; Lake Tahoe, California and Nevada; and Berry Creek, Oregon (Table 4). The difference among the three groups was significant (1-way ANOVA, $P<0.01$). However, when the Delta values were compared with either those from Berry Creek or Lake Tahoe, the mean numbers of eggs per female between 80 and 90 mm was not significantly different (t-test, $P>0.05$).

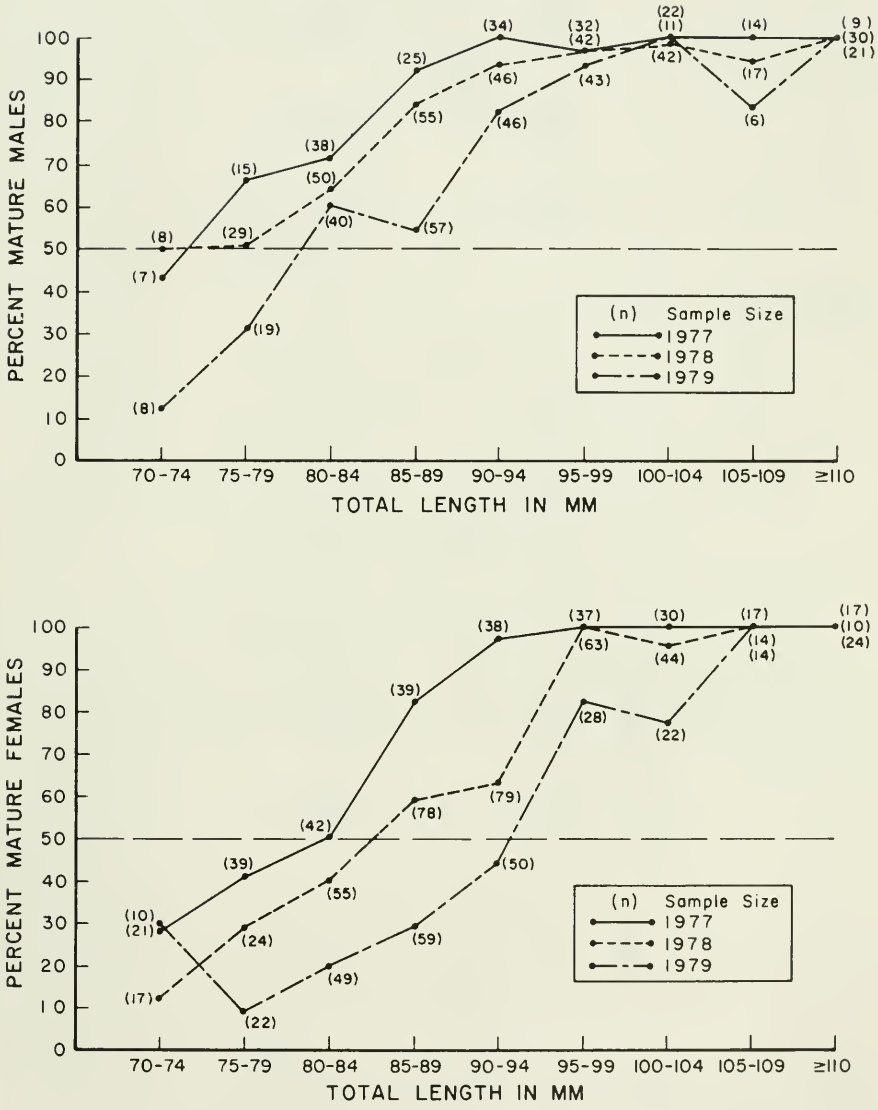


FIGURE 3. Relationship between length and maturity of male and female Delta crayfish.

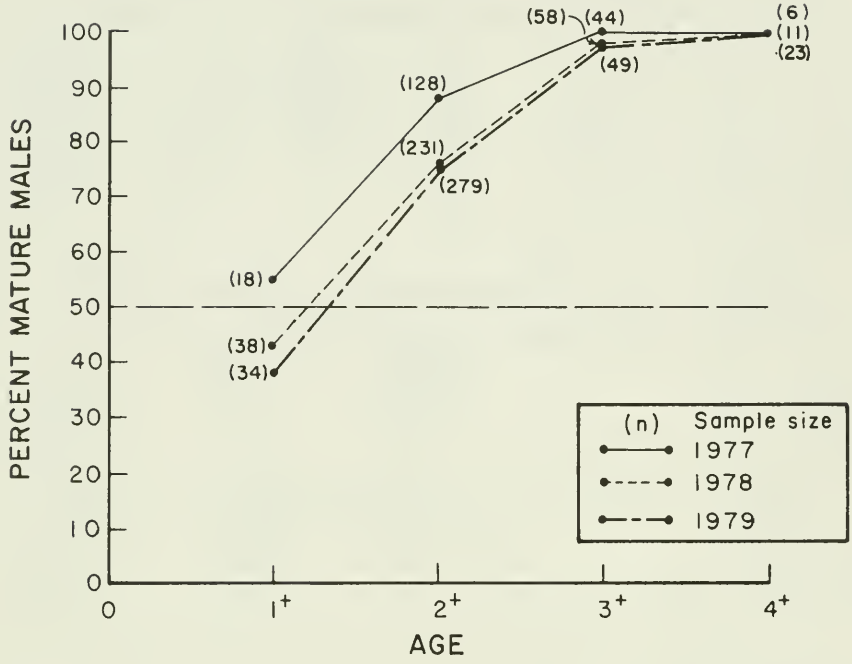
TABLE 2. Relationship Between Age and State of Maturity of Delta Crayfish

Female

Year	1+ Total sample	1+ Number mature	1+ Percent mature	2+ Total sample	2+ Number mature	2+ Percent mature	3+ Total sample	3+ Number mature	3+ Percent mature	4+ Total sample	4+ Percent mature
1977	62	22	35.5	162	130	80.2	63	63	100	11	100
1978	43	12	27.9	271	177	65.3	73	71	97.3	4	100
1979	32	5	15.6	182	67	36.8	52	46	88.5	13	100

Male

Year	1+ Total sample	1+ Number mature	1+ Percent mature	2+ Total sample	2+ Number mature	2+ Percent mature	3+ Total sample	3+ Number mature	3+ Percent mature	4+ Total sample	4+ Percent mature
1977	18	10	55.6	128	113	88.3	44	44	100	6	100
1978	38	16	42.1	231	176	76.2	58	57	98.3	11	100
1979	34	13	38.2	279	209	74.9	49	48	98.0	23	100



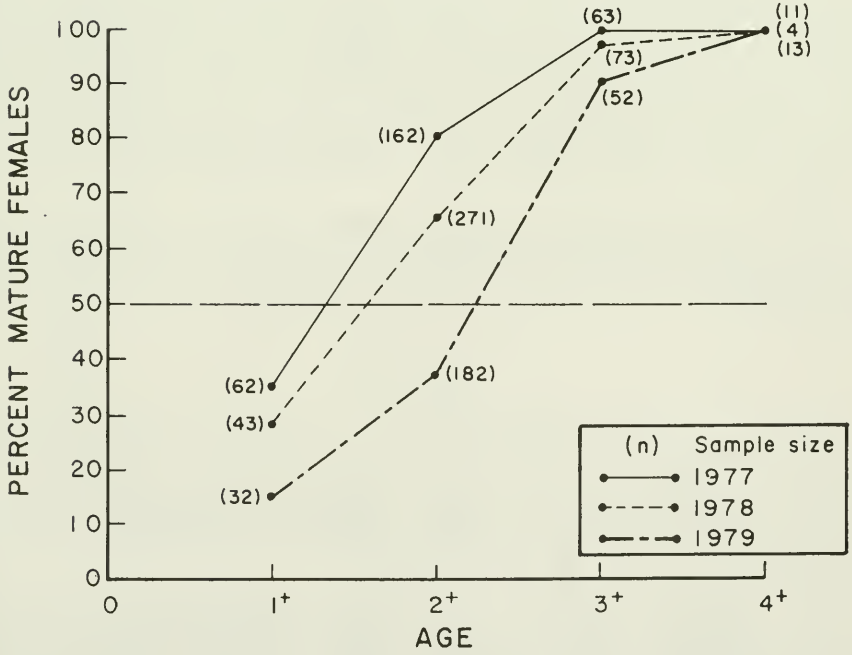


FIGURE 4. Relationship between age and maturity of male and female Delta crayfish.

TABLE 3. Mean Numbers of Pleopod Eggs and Sample Sizes for Delta Crayfish

Year	*Number of 2+ crayfish*	*Mean number of eggs*	*Number of 3+ and older crayfish*	*Mean number of eggs*	*Mean number of eggs per mm length of the female*
1975	31	199.5	29	279.4	2.29
1977	114	166.3	29	206.0	1.94
1978	53	195.5	63	237.3	2.20

TABLE 4. Fecundity Comparisons of Crayfish from Different Locations

Ovarian eggs per female between 80 and 90 mm

Location	*Number of crayfish*	*Mean number of eggs*	*Range*
Lake Tahoe*	23	144.5	110–175
Berry Creek†	13	175.4	140–218
Delta	12	161.2	88–239

Pleopod eggs per female between 100 and 105 mm

Location	*Number of crayfish*	*Mean number of eggs*	*Range*
Lake Tahoe*	13	152.5	120–179
Rögle Pond‡	20	164.6	80–242
Delta	64	224.8	41–340

* From Flint (1975).
† From Mason (1963).
‡ From Abrahamsson (1971).

Similarly, mean number of pleopod eggs per female between 100 and 105 mm was compared for crayfish from the Delta, Lake Tahoe, and from Rögle Pond, Sweden (Table 4). The mean number of pleopod eggs per female among the three groups was significantly different, with the Delta mean significantly greater than means for either Lake Tahoe or Rögle Pond (1-way ANOVA, $P < 0.01$) (t-test, 1-tail, $P < 0.01$). However, there was no significant difference between mean numbers of eggs per female from Lake Tahoe and Rögle Pond (t-test, $P > 0.05$).

Comparing mean numbers of pleopod eggs per female for 1975, 1977, and 1978 with mean numbers of ovarian eggs per female for 1979 indicates that in the Delta, ovigerous females carry from 61.6 to 82.2% of the mean ovarian egg complement.

DISCUSSION

Growth

Growth is variable among populations of *P. leniusculus* described in the literature. Differences were noted in time of hatching, length increase per molt, frequency of molting, and in the growth rate between the sexes (Table 5). It is generally agreed, however, that water temperature is an important factor in crayfish growth, with water temperatures of about 21°C promoting the most rapid growth (Westman 1973, Mason 1978).

Only 19 crayfish identified as young-of-the-year were taken in trap catches between June and December 1977 (Table 6). This small sample did not allow quantitative analysis of age 0+ growth. However, these data combined with that of other studies provides enough indirect evidence to hypothesize a rapid

TABLE 5. Life History Parameters of Various Populations of *Pacifastacus leniusculus* Recorded in the Literature.

Location	*Author*	*Maximum Size (mm)*	*Time of hatching*	*Size (mm) at age*					*Number of molts per year*	*Growth per molt (mm)*	*Age at maturity*	*Mean number of ovarian eggs (range)*	*Mean number of Pleopod eggs (range)*
				0+	*1+*	*2+*	*3+*	*4+*					
Lake Tahoe, Calif.-Nevada	Abrahamsson and Goldman 1970	–	–	≈ ≤ 38	≈40–57	≈60–76	≈ > 77	–	–	–	♂ = 2+ ♀ = 3+	–	110
Lake Tahoe Calif.-Nevada	Flint 1975	131	July	32	49	68	78	84	>77 mm = once	1+ = 6.8 2+ = 6.9	3+	152 (79–239)	120 (52–189)
Deep River, Washington	Miller 1960	150 to 180	late April to late May	–	–	–	–	–	2 usually, 3 with higher water temps.	–	1+ usually, 0+ for some	–	85–89 mm = 158 (137–178), 107–112 mm = 297 (202–380)
Berry Creek, Oregon	Mason 1963, 1975	108	late April to early June	13–21	24–46	50–60	–	–	0+ = 8 to 9 times; > 80 mm = once	3.56 mm between 10 and 55 mm; 6.4 mm between 60 and 105 mm	3+ for most, 2+ for fast growers	145 (90–251)	–
Rögle Pond, Sweden	Abrahamsson 1971	≈127	–	♂ = 40, ♀ = 39	♂ = 82, ♀ = 79	♂ = 102, ♀ = 97	–	–	2 per summer for adults	♂ = 10 ♀ = 8	♂ = 1+ ♀ = 2+	–	(≈50–260)
Sweden	Brink 1975	≈180	–	–	♂ = 92, ♀ = 87	–	♂ = 122, ♀ = 115	–	–	–	♂ = 2+ ♀ = 1+	–	–
Lake Nevardas, Lithuania	Cukerzis 1978	–	–	–	♀ ≈53	≈82	♀ ≈106	≈126	–	–	–	–	–
Poland	Kossakoski and Kossakoski 1978	–	–	50	80	100	125	–	–	–	2+	–	–
Lake Slickdampi, Finland	Westman and Pursiainen 1978	–	–	–	–	–	♂ = 115–130	–	–	–	–	–	–
Sacramento-San Joaquin Delta, Calif.	this study	155	late March to late April	≤64	65–78	79–98	99–112	≥113	≈13 for 0+; 3 for 1+ and some 2+; 2 for all others but largest	6.6 between 64 and 117 mm	♂ = 2+ for most, 1+ for many; ♀ = 2+ for some to most, 1+ for some	281 (88–560)	201 (3–548)

growth rate for 0+ *P. leniusculus* in the Delta region. Andrews (1907) raised seven *P. leniusculus* in the laboratory from eggs to lengths of 52 to 63 mm ($\bar{x}$ = 57 mm) in 5 months and 1 week. Brink (1975) found that a cohort of 0+ *P. leniusculus* planted at 10 to 15 mm grew to 92 mm (♂) and 87 mm (♀) by age 1+. These examples illustrate the potential of *P. leniusculus* for extremely rapid growth during the first two years of life.

TABLE 6. Length (in mm) of Young-of-the-Year Crayfish Taken in Trap Catches Between June and December 1977.

June	*August*	*September*	*December*
23	31	55	59
24	39	55	60
25	39	56	65
27	45	58	65
29	47	$\bar{x}$=56.0	$\bar{x}$=62.2
$\bar{x}$=25.6	47		
	$\bar{x}$=41.3		

The observed grand mean length increase per molt of 6.6 mm for crayfish ≥ 64 mm in the Delta is close to values obtained by Flint (1975) for Lake Tahoe and Mason (1975) for Berry Creek. Mason (1975) also found a grand mean length increase per molt of 3.56 mm for crayfish between 10 and 55 mm. Assuming a similar length increase per molt for 0+ individuals in the Delta, and assuming they are 10 mm TL when they take up independent existence in April to early May, they must undergo approximately 13 molts to reach 56 mm in September. Assuming that the 6 mm length increase per molt Mason (1975) observed for 55 mm individuals in Berry Creek is duplicated in the Delta, it would take one molt between September and December to reach the mean length of 62.2 mm TL observed in December.

This rapid growth rate is not unprecedented given the early spring warming which contributes to early hatching, and the mean summer water temperature of 21.5°C (Calif. Dep. Water Resources 1962, 1977, 1978, 1979; U. S. Dep. Interior 1972, 1973, 1974) which contributes to increased molt frequency (Miller 1960, Emadi 1974, Mason 1978).

Although the length increase per molt for crayfish ≥64 mm was the same for both sexes, as males increase in length they became significantly heavier than females. Miller (1960) and Mason (1963) attributed this differential weight gain to the allometric chelae growth exhibited by mature males. Calculated regression equations for Delta crayfish were close to those obtained by both Mason (1963) in Oregon, and Miller and Van Hyning (1962) in two rivers in Washington. Miller and Van Hyning (1962) concluded that the length-weight relationship of *P. lenisuculus* does not vary noticeably among widely separated populations. The Delta data support that conclusion.

Age Composition

Determining crayfish age is difficult. Analysis of size frequency distributions is helpful, but the wide variation in lengths within any age class, and the overlap of sizes between age classes, are long-recognized problems (Andrews 1907, Miller 1960). Assigning discreet boundaries between age classes is arbitrary. Boundaries are presented here only as a tool for analysis, and undue significance should not be given to any particular age class boundary. Growth in number of

molts per year and length increases per molt is assumed to be relatively constant over the period and area of study.

Maturity

The great variation in the relationship between size and state of maturity of female crayfish does not appear to be peculiar to the Delta region or even to *P. leniusculus*. Abrahamsson and Goldman (1970) found that 50% of the females in Lake Tahoe >81 mm were sexually mature, while Flint (1975) reported that 75% of the Lake Tahoe females >69 mm were sexually mature. Flint also found a difference in size at maturity among crayfish taken from the three transects he studied in Lake Tahoe. He attributed smaller size at maturity to lack of suitable cover for larger individuals and greater population density which resulted in a population of stunted adults. Johnson (1971) reported a significant difference in the percentage of mature age 1+ *P. l. trowbridgii* in Fern Lake, Washington, between 1968 and 1969. He attributed the higher value in 1968 to artificial fertilization. Huner and Romaire (1978) stated that *Procambarus clarkii* males may reach sexual maturity at lengths that range from 50 to 115 mm, with a generally smaller size at maturity for males from stressed environments. Differences were noted both among broad habitat types and among microhabitats.

Age at maturity for *P. leniusculus* also varies considerably for populations reported in the literature. Generally, crayfish mature earlier in areas where they exhibit faster growth rates (Table 5). The early maturity in the Delta region is consistent with the rapid crayfish growth rate.

The variation in age and size at maturity is an example of the adaptability of crayfish to different habitats and no doubt to subtle or substantial changes within their habitats. The causes of the observed fluctuations in the onset of maturity in the Delta are unknown. However, the two most conspicuous changes that occurred during the years sampled were a drop in the commercial harvest from 243,000 kg in 1977 to 47,000 kg in 1978 because of marketing problems (McGriff 1983), and a severe drought in 1976 and 1977 that reduced flows through the Delta by up to 92% (Table 7). If a large harvest combined with drought conditions can be considered a stress on the population, then early maturity in 1977 is consistent with the conclusions of Huner and Romaire (1978) for *Procambarus clarkii* males.

TABLE 7. Water Flows in Liters Per Second Through the Sacramento-San Joaquin Delta from April Through October

	Apr	*May*	*Jun*	*Jul*	*Aug*	*Sept*	*Oct*
21-year mean 1956–1977	1,092,812	743,343	457,991	188,640	191,500	308,801	352,272
1976 (% decline)	250,151	115,149	110,873	122,994	127,695	103,934	102,603
	(77.1)	(84.5)	(75.8)	(34.8)	(33.3)	(66.3)	(70.9)
1977 (% decline)	87,311	113,252	71,395	90,964	71,196	79,041	58,764
	(92.0)	(84.8)	(84.4)	(51.8)	(62.8)	(74.4)	(83.3)

Fecundity

Fecundity data were collected in the fall of 1975, 1977, and 1978. Since crayfish eggs hatch the following spring, they represent the 1976, 1978, and 1979 year classes, respectively.

The commercial fishery harvests primarily ages 2+ and 3+ crayfish ($\bar{x}$ =82.7%; range=79.6 to 86.6% of the total catch) (McGriff 1983). Thus, a weak

year class would first appear in the fishery 2 years after hatching. Commercial catch statistics from 1976, 1977, and 1980 show that 2 year olds accounted for a mean of 42.2% (range=40.2 to 46.1%) of the the total catch. In 1978 and 1979, however, 2-yr olds constituted only 32.4% and 29.0% of the harvest, respectively (Table 8). There is an apparent anomaly if these two depressed year classes are traced back to the year eggs were extruded. Fecundity estimates show that significantly fewer eggs per female were produced in 1977 (1978 year class), yet the commercial catch statistics from 1980 show the 1978 year class of age 2+ individuals to be of normal strength. Although the number of eggs per female produced in 1975 (1976 year class) was the highest of the 3 years sampled for fecundity data, the catch records from 1978 indicate a weakened 2+ year class. Any explanation can be only speculative, but there is enough circumstantial support, and the conclusions are of sufficient importance to justify conjecture.

TABLE 8. Percent Age Composition of the Commercial Delta Crayfish Catch.

	1975	*1976*	*1977*	*1978*	*1979*	*1980*
Ages 0 and 1	16.6	1.4	2.9	0.4	0.4	1.4
Age 2	60.4	40.4	46.1	32.4	29.0	40.2
Age 3	19.2	40.4	38.7	54.2	52.1	42.9
Ages 4 and older	3.8	17.8	12.3	13.0	18.5	15.5
Total	100	100	100	100	100	100

Both 1976 and 1977 were severe drought years in California. Progeny from eggs extruded in 1975 (1976 year class), spent their 0+ and 1+ years in flows that were reduced from 33.3 to 92.0% of the 21-yr mean for the April to October period in the Delta (Table 7). The 1976 year class is poorly represented in the commercial catch as 2-yr olds. I have no estimates of fecundity for 1976 (1977 year catch), but these crayfish spent their first year in flows that were reduced 51.8 to 92.0% from normal, and this year class is poorly represented in the commercial catch as 2-yr olds. Significantly fewer eggs per female were produced in 1977 (1978 year class) but these crayfish spent their first two years under normal water conditions and as 2-yr olds they exhibited typical year class strength.

There may be other factors that interacted to affect fecundity and the strength of these three year classes. For example, Momot and Gowing (1977) found the number of pleopod eggs per female negatively correlated to population density. However, the drought, with its associated low flows, was sufficiently outstanding to have played a major role. The 1976 and 1977 year classes may have been weakened by decreased survival of juveniles during the adverse drought conditions while the 1978 year class compensated for decreased fecundity during the drought with increased survival of juveniles when conditions improved. In addition, although significantly fewer eggs per female were produced in 1977, there was a higher level of maturity among smaller sizes and younger ages that year. Therefore, the absolute fecundity level, in total eggs produced Delta-wide, may not have been reduced. This implies that *P. leniusculus* is very adaptable, responding quickly to changes in environment and recovering rapidly when favorable conditions return.

Mean ovarian egg counts per female of Delta crayfish between 80 and 90 mm (161.2) were intermediate between those from Lake Tahoe (144.5), and Berry Creek (175.4). Therefore, there does not appear to be any increase in fecundity

in the Delta population in response to the commercial fishery.

Comparison of the mean numbers of pleopod eggs per female between 100 and 105 mm, shows very close means for Lake Tahoe and Rögle Pond, Sweden, with a much greater mean for the Delta. It is tempting to conclude that commercial fishing in the Delta is responsible for the increase in mean pleopod egg counts, except that the Delta mean agrees very closely with fecundity estimates for 100 to 105 mm females from Cowichan River and Lower Pitt Lake, British Columbia (Mason 1977), where there is no commercial fishing.

CONCLUSIONS

This study was undertaken primarily to gather sufficient life history information on *P. leniusculus* to develop a management plan for the commercial fishery in the Delta. Many variables operated during the years of this study. Therefore, I can only speculate on the effects the commercial harvest and Delta water flow had on maturity and fecundity. They are presented here as a basis for further study.

The adaptability of crayfish and their annual variability in growth, maturity, and fecundity have important implications for future crayfish studies and management plans. Any study of a wild population should be designed to collect replicate data over several years, as a single year's data may be misleading.

Our goal should be to obtain life history data for populations from a sufficient number of diverse habitats so it will be possible to predict major life history parameters based on characteristics of the habitat in question.

ACKNOWLEDGMENTS

I wish to thank D. Najima, D. Erickson, J. Loris, R. March, S. Smith, and D. Knudsen for their help with the field work. I wish to particularly thank S. Shimizu, whose work in cooperation with the Department was invaluable. the prompt assistance of R. Carpenter and P. Law with the statistical analysis is very much appreciated. And I am grateful to A. Cordone, L. Eng, E. Gleason, and K. Hashagen for their critical review of the manuscript.

LITERATURE CITED

Abrahamsson, S. A. A. 1965. A method of marking crayfish *Astacus astacus* Linne in population studies. Oikos, 16: 228–231.

_____. 1971. Density, growth, and reproduction in populations of *Astacus astacus* and *Pacifastacus leniusculus* in an isolated pond. Oikos, 122: 373–380.

Abrahamsson, S. A. A., and C. R. Goldman. 1970. Distribution, density, and production of the crayfish *Pacifastacus leniusculus* (Dana) in Lake Tahoe, California-Nevada. Oikos, 21: 83–91.

Andrews, E. A. 1907. The young of the crayfishes *Astacus* and *Cambarus*. Smithsonian Contrib. to Knowledge 35(1718): 1–79.

Brink, P. 1975. Crayfish in Sweden. Pages 77–85 *in* J. W. Avault, Jr., ed. Freshwater Crayfish. Louisiana State Univ., Baton Rouge, Louisiana. 676 p.

California Department of Water Resources. 1962. Sacramento River water pollution survey. Bull. 111 plus appendices A–D.

_____. 1977. Sacramento-San Joaquin Delta water quality surveillance program 1976. Monitoring results pursuant to conditions set forth in Delta water rights decision 1379. Vol. I (Methodology, field data, and chemical analyses). 304 p.

_____. 1978. Sacramento-San Joaquin Delta water quality surveillance program 1977. Monitoring results pursuant to conditions set forth in Delta water rights decision 1379. Vol. I (Methodology, field data, and chemical analyses). 300 p.

_____. 1979. Sacramento-San Joaquin Delta water quality surveillance program 1978. Monitoring results pursuant to conditions set forth in Delta water rights decision 1485. Vol. I (Methodology, field data, and chemical analyses). 276 p.

Cassie, R. M. 1954. Some uses of probability paper in the analysis of size frequency distributions. Aust. J. Mar. Freshw. Res. 3: 513–522.

Cukerzis, J. M. 1978. On acclimatization of *Pacifastacus leniusculus* Dana in an isolated lake. Pages 445–450 *in* P. J. Laurent, ed. Freshwater Crayfish 4. Institut National de la Recherche Agronomique. Thonon-les-Bains, France. 473 p.

Emadi, H. 1974. Culturing conditions and their effects on survival and growth of the crayfish *Pacifastacus leniusculus trowbridgii* (Stimpson). Dissertation. Oregon State Univ., Corvallis. 152 p. Available from: University Microfilms, Ann Arbor, MI; Publication no. 74-23,434.

Flint, R. W. 1975. The natural history, ecology, and production of the crayfish *Pacifastacus leniusculus,* in a subalpine lacustrine environment. Dissertation. Univ. of Calif. Davis. 157 p. Available from: University Microfilms, Ann Arbor, MI; Publication no. 76-1782.

Huner, J. V., and R. P. Romaire. 1978. Size at maturity as a means of comparing populations of *Procambarus clarkii* (Girard) (Crustacea, Decapoda) from different habitats. Pages 53–64 *in* P. J. Laurent, ed. Freshwater Crayfish 4. Institut National de la Recherche Agronomique. Thonon-les-Bains, France. 473 p.

Johnson, E. A. 1971. Biological studies on the crayfish, *Pacifastacus leniusculus trowbridgeii* (Stimpson), in Fern Lake, Washington. Thesis. Univ. of Wash., Seattle. 76 p.

Kelley, D. W. 1966. Description of the Sacramento-San Joaquin Estuary. Pages 8–17 *in* D. W. Kelley, compiler. Ecological studies of the Sacramento-San Joaquin Estuary. Part 1. Zooplankton, zoobenthos, and fishes of San Pablo and Suisun bays, zooplankton, and zoobenthos of the Delta. Calif. Dept. Fish and Game, Fish Bull. (133): 1–133.

Kossakowski, J. M. M., and G. Kossakowski. 1978. The first introduction of the crayfish, *Pacifastacus leniusculus* Dana into Polish waters. Pages 195–196 *in* P. J. Laurent, ed. Freshwater Crayfish 4. Institut National de la Recherche Agronomique. Thonon-les-Bains, France. 473 p. Abstract only.

Mason, J. C. 1963. Life history and production of the crayfish *Pacifastacus leniusculus trowbridgii* (Stimpson), in a small woodland stream. Thesis. Oregon St. Univ., Corvallis. 204 p.

_____. 1975. Crayfish production in a small woodland stream. Pages 449–479 *in* J. W. Avault Jr., ed. Freshwater Crayfish. Louisiana St. Univ. Baton Rouge, Louisiana. 676 p.

_____. 1977. Reproduction efficiency of *Pacifastacus leniusculus* (Dana) in culture. Pages 101–117 *in* O. V. Lindqvist, ed. Freshwater Crayfish 3. Univ. of Kuopio, Kuopio, Finland. 504 p.

_____. 1978. Effects of temperature, photoperiod, substrate, and shelter on survival, growth, and biomass accumulation of juvenile *Pacifastacus leniusculus* in culture. Pages 73–82 *in* P. J. Laurent, ed. Freshwater Crayfish 4. Institut National de la Recherche Agronomique. Thonon-les-Bains, France. 472 p.

McGriff, D. A. 1983. The commercial fishery for *Pacifastacus leniusculus* Dana in the Sacramento-San Joaquin Delta *in* C. R. Goldman, ed. Freshwater Crayfish 5. AUI Publishing Co., Westport, Conn. In press.

Miller, G. C. 1960. The taxonomy and certain biological aspects of the crayfish of Oregon and Washington. Thesis. Oregon State Coll. Corvallis. 216 p.

Miller, G. C., and J. M. Van Hyning. 1962. The commercial fishery for freshwater crawfish, *Pacifastacus leniusculus* (Astacidae), in Oregon 1893–1956. Fish Comm. of Oregon, Res. Repts. 2: 77–89.

Momot, W. T. and H. Gowing. 1977. Production and population dynamics of the crayfish *Orconectes virilis* in three Michigan lakes. Can., Fish. Res. Bd., J., 34(11): 2041–2055.

Osborne, D. A. 1977. The crayfish—or by any other name—becoming big fishery. Outdoor California, 38(5): 4–6.

_____. 1978. The commercial crayfish market collapse of 1978. Outdoor California, 39(6): 16–17.

Shimizu S. J. and C. R. Goldman. 1983. *Pacifastacus leniusculus* (Dana) production in the Sacramento River *in* C. R. Goldman, ed. Freshwater Crayfish 5. AUI Publishing Co., Westport, Conn. In press.

U. S. Dept. of the Interior, Bureau of Reclamation. 1972. Delta-Suisun Bay surveillance program. A progress report on the Delta San Luis drain surveillance portion of the program. Appendix A—Methods, Appendix B—Data. Mid-Pacific Region Water Quality Branch. Sacramento, California.

_____. 1973. Delta-Suisun Bay surveillance program. A progress report on the peripheral canal study program portion of the program. Data appendix. Mid-Pacific Region Water Quality Branch. Sacramento, California.

_____. 1974. Delta-Suisun Bay surveillance program. A water quality progress report on the Central Valley operations sampling program. Methods appendix, Data appendix. Mid-Pacific Region Water Quality Branch. Sacramento, California.

Westman. L. 1973. Cultivation of the American crayfish, *Pacifastacus leniusculus.* Pages 211–220 *in* S.A.A. Abrahamsson, ed. Freshwater Crayfish. Studentlitteratur. Lund, Sweden. 252 p.

Westman, K., and M. Pursiainen. 1978. Development of the European crayfish *Astacus astacus* (L.) and the American crayfish *Pacifastacus leniusculus* (Dana) populations in a small Finnish lake. Pages 243–250 *in* P. J. Laurent, ed. Freshwater Crayfish 4. Institut National de la Recherche Agronomique. Thonon-les-Bains, France. 473 p.

Calif. Fish and Game 69(4): 243–252 1983

TAGGING MATERIALS AND METHODS FOR SEA OTTERS, *ENHYDRA LUTRIS*[1]

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Previously the tags used on sea otters with good retention characteristics have either not been or long remained uniquely identifiable. Initially, attachments of highly visible plastic tags in the webbing of the sea otter's hind feet resulted in relatively poor retention. A new technique of double anchoring these plastic tags significantly improves retention. Use of a small monel tag placed in the sea otter's ear shows promise as a permanent mark.

INTRODUCTION

Artificial marks or tags applied to wild animals allow researchers to identify individuals and improve their ability to investigate life history parameters. Knowledge, thus gained, facilitates more enlightened management. The hind foot (flipper) of the sea otter has usually been selected as the site for tagging because it is large and webbed, frequently visible since otters commonly float on their backs, and marking there appears to elicit negligible effects on behavior (Ribic 1981). Collars have met with only partial success because the otter's thick tapering neck does not lend itself well to these devices (Loughlin 1978, Costa and Kooyman 1981). Otters have small ears that can probably accomodate only small tags.

HISTORICAL TECHNIQUES

From 1956 to the present several different researchers in both Alaska and California have flipper tagged sea otters using a number of different tags with varying degrees of success (Table 1). Kenyon (1969), between 1956 and 1963, marked 224 sea otters in the hind foot webbing with monel metal tags, some of which had colored plastic strips attached to aid in field identification. Tag loss was not estimated, but at least one detached plastic strip was found at a hauling ground six days after tagging. Some of these tags remained in place for at least three years.

Odemar and Wilson (1969) were aware of Kenyon's use of monel tags but believed, as we do, that individual identification (through a spotting scope) was

[1] Accepted for publication September 1982.

also of paramount importance. Working with captive otters, they used a variety of tags constructed of plastic, nylon, monel, and aluminum and found generally poor retention. They also used several different sizes and shapes of tags, mostly aluminum, on 17 sea otters in the wild during a transplant test in 1969. Follow-up observations were limited and tag loss measurements were not attempted.

Wild and Ames (1974) reported on 26 sea otters that were single tagged in 1970 through 1972 with self-piercing, painted, aluminum tags. Tag loss measurement was not attempted, however, loss could have been considerable since follow-up sightings decreased rapidly following tagging.

Loughlin (1978) continued to use aluminum tags, but to facilitate identifying a large number of individuals he placed tags between various toes in both hind feet and painted them a variety of colors. He considered tag loss to be quite low but did not measure it precisely.

Loughlin (1978) also reported that lost tags left a "rip" in the flipper webbing. During the present study (1977 through 1981), we have observed a mechanism by which some and perhaps all of these "rips" occur. Sea otters sometimes bite opposite sides of an aluminum tag causing the two halves to bend together pinching the tissue sandwiched between. If the bending becomes severe, the tissue between the tag halves dies and the tag falls off. We know of at least three tags lost in this manner. A fourth tag in the process of being lost by this mechanism was observed on a dead otter.

Despite retention problems for many individuals, aluminum tags have remained firmly affixed to both hind feet in at least two animals for over five years (as of November 1981). An animal tagged by Wild and Ames and later by Loughlin had carried one tag for six years 8½ months and the other for three years seven months at the time of its death in August 1979. A serious drawback to painted aluminum or any painted metal tag is that once the paint is removed (chewed off) the tag is no longer uniquely identifiable at a distance.

RECENT TECHNIQUES

Plastic Tagging

During the present study, we used plastic tags [original cattle size ear tags made by Temple Tag Company (Any reference to trade names or manufacturers does not imply endorsement by the California Department of Fish and Game.)]. "Temple" tags are constructed of hard plastic available in a variety of solid colors. These tags were preliminarily tested in Alaska by the United States Fish and Wildlife Service (FWS) in 1977 (Ancel Johnson, USFWS, pers. commun.) The FWS has continued to use "Temple" tags in both Alaska and California. They are easily applied by punching or cutting a hole in the webbing and inserting the tag (Figure 1). One hundred forty-two sea otters were double tagged using this technique between September 1977 and September 1979. Early in our tagging program, some of these otters were observed in the wild with only one tag in place. To date (November 1981), a minimum of 25 different sea otters have been observed with single plastic tags. The actual number is obviously higher; once an animal loses a tag, it usually can no longer be individually identified through a telescope. Twelve otters are known to have lost both of their flipper tags.

TABLE 1. Tagging Materials and Methods that Have Been Used on Sea Otter Flippers

Researcher(s) Dates	*Tags, tagging techniques, number of otters tagged and (Number of feet tagged)*	*Retention characteristics*	*Visibility characteristics*	*Comments*
Kenyon, United States Fish and Wildlife Service (FWS) 1956– 1963	Monel self piercing "cattle ear size" and "sheep ear size" by National Band and Tag Company	Probably very good. At least 3 years in one animal.	Probably poor.	Individual identification at a distance not possible. Little follow up information.
	Same as above with colored plastic strips attached. All single anchored. N=224(224)	Colored strips probably detached very quicklly	Probably fair.	
Odemar and Wilson, California Department of Fish and Game (DFG) 1969	Plastic "Rototags" by Nasco.	5 minutes to 50 days.	Unknown.	Most experiments done on captive animals. Little follow up information on otters in the wild.
	Vinyl "Tough Ply Ear Tags" by Nasco.	12 days.	Unknown.	
	Dacron and plastic "Simplicity Ear Tag" by Simplicity Ear Tag Co. and modified by Lavan Kroger of Washington State College.	24 to 26 days.	Unknown.	
	"Simplicity Tag" anchored with a small monel tag.	Unknown-probably poor.	Good.	
	Aluminum "Ear Button" tag by Nasco.	21 days.	Unknown.	
	Nylon flagging.	Probably poor.	Probably good.	
	Aluminum self piercing "Perfect Shaped Ear Tag" by Nasco.	At least 169 days in captivity, at least 10 months in the wild.	Good.	
	Monel self piercing tag by National Band and Tag Company.	Probably good.	Probably poor.	
	Some single tagged, some double tagged some repeatedly tagged. All single anchored. N=20(34)			

TABLE 1. Tagging Materials and Methods that Have Been Used on Sea Otter Flippers—Continued

Researcher(s) Dates	*Tags, tagging techniques, number of otters tagged and (Number of feet tagged)*	*Retention characteristics*	*Visibility characteristics*	*Comments*
Wild and Ames, DFG 1970–1972	Aluminum self piercing tag "Cattle Size" (1½ inch disk) by Salt Lake Stamp Company. Painted a single color. Single anchored and single tagged. N=26(26)	Variable—from a few weeks to at least 6¼ years. Pinching of webbing due to chewing a problem.	Good while paint lasts; fair thereafter.	Identification from a distance to one of two groups and sex possible as long as paint lasts. Sex identification only thereafter.
Loughlin, University of Calif. at Los Angeles. 1975–1976	Same as above but tags painted variously. One tag in each hind foot. Single anchored. N=27(54)	Same as above.	Same as above.	Individuals identifiable from a distance as long as paint lasts; with difficulty thereafter.
Present Study, DFG 1977–1981 continuing	Solid colored plastic tag—Original "Temple Tag", cattle size, by Temple Tag Company. Double tagged, single anchored. N=58(116)	Variable—from a few weeks to about 4 years as of Nov. 1981.	Fair to excellent. Some of the 12 colors used are much more visible than others. Color fading a problem in some tags after 2 to 3½ years.	Individuals identifiable from a distance as long as both tags are seen. Identifiable to area and sex from right foot tag only.
	Same as above with open end of tag glued closed. N=84(168)	Same as above.		
	Same as above, tag modified—double anchored, screwed and glued. N=93(186)	Still variable; significant improvement. Minimum time 6–8 mos.		
Sea World, 1977–1981 continuing	"Temple Tag", sheep size and cattle size. Single anchored. N≃15(≈ 20)	A few days to a few months.		
	Same as above, double anchored. N=2(2)	19 mos. and 23 mos. as of Nov. 1981.	Same as above.	Captive animals.
FWS 1977–1981 continuing	"Temple Tag".	DATA TO BE PUBLISHED SEPARATELY		
	Modified "Temple Tag".			
	Other tags?			

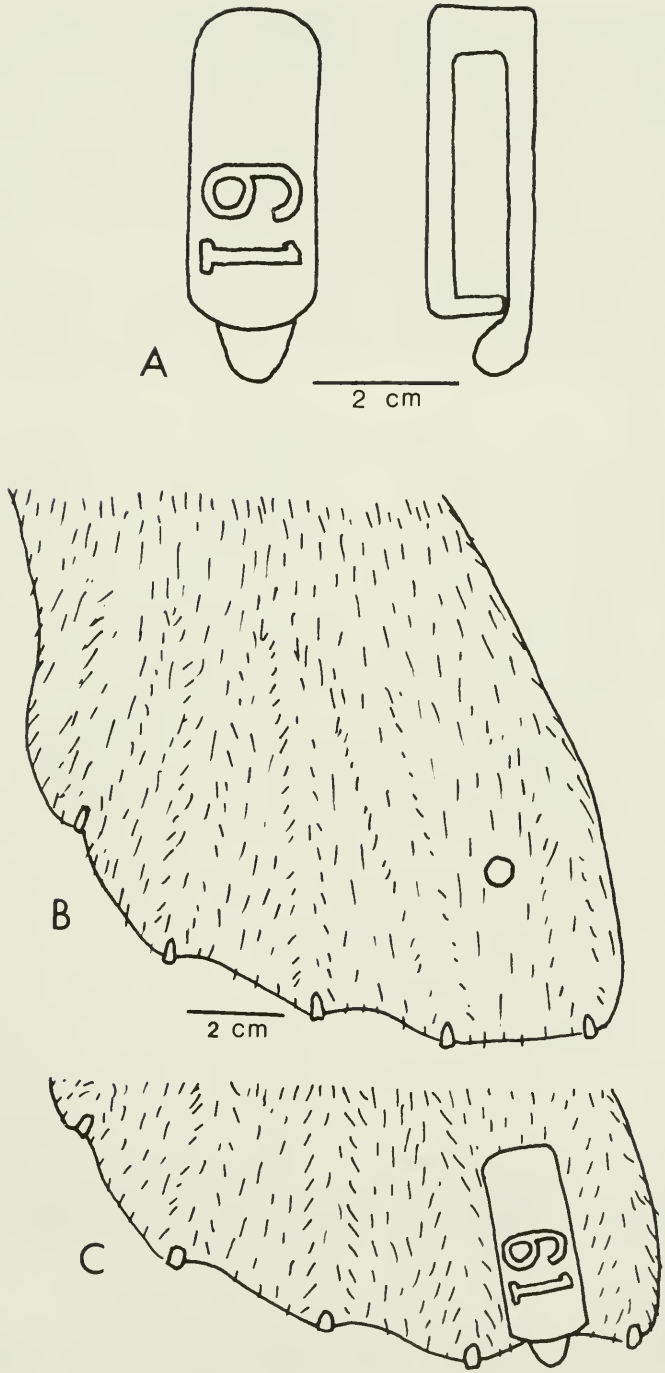

FIGURE 1. (A) Top and side view of "Temple" plastic tag. (B) Left hind foot of a sea otter with a hole punched in the webbing between toes 4 and 5, and (C) the same foot with tag installed.

Additionally, nine otters have been tagged at Sea World, San Diego, California (SWSD). All of these captives have removed tags (some repeatedly) in a few weeks to a few months. One tag was drilled and had the open end secured with a piece of stainless steel wire. That tag was missing in less than seven months.

Observations of damaged tags suggest that missing tags are flexed to the breaking point and thereby lost. Perhaps some are simply pulled out. In either case, they are removed without tearing the hind foot webbing. We initially attempted to improve tag retention by gluing the open end of the tag closed. The only adequate glue found was acrylic plastic cement (weld-on # 4 made by Industrial Polychemical Service). Under laboratory conditions tags could be firmly glued. However, in the field our attempts to glue tags were unsuccessful; of seven animals with double tags as described above (that were either recaptured or recovered dead) none had a tag that was still glued closed.

Double Anchoring

In September 1979, we began using a technique of double anchoring "Temple" tags in the hind foot webbing. This is done by placing the tag further into the webbing and punching two holes approximately 35 mm apart (Figure 2). The tag is then inserted through the proximal hole with the open end meeting at the distal hole. Each tag is predrilled (using a number 46 drill and a counter sink) making it possible to fasten the open end with a small nylon screw (flat head, nylon screw, size $2\frac{5}{6} \times \frac{1}{2}$ inch). Acrylic plastic cement is applied liberally in the hole and the screw is inserted with a pair of pliers. We placed two tags each on 93 sea otters in the wild using this double anchoring technique and as of November 1981 had observed only six tags lost. Additionally, three animals, at liberty six to eleven months, had chewed the screwed-and-glued end of one of their tags off, but the tags were still in place. In December 1979, two captive otters had plastic tags "double anchored." One was lost after 21 months; the other remained in place as of November 1981 (Tom Goff, SWSD, pers. commun).

Tag resighting data also was used to compare tag loss rates for the three plastic tag attachment methods used during this study. An estimate of the rate of tag loss may be generated by assuming that the longer a tagged otter remains unobserved the higher the likelihood that its tags are lost. The accuracy of this assumption could be heavily influenced by differences in observation effort, emigration, and mortality rates. We attempted to minimize the effect of these sources of error by using tag sighting data only from areas with fairly uniform observational effort and with similar sea otter social structure (Monterey and San Simeon areas). Sea otters were "Temple" tagged sporadically during a 50-month period (as of November 1981). We assumed that the time of year a tag was attached did not influence its tendency to be shed. An eight month gap in tagging effort occurred after 2 November 1979. Using resighting data from otters with "double anchored" tags applied by this date or earlier, allowed 595 days to observe the animals tagged the shortest length of time (as of June 1981). We therefore used only the first 595 potential observation days for each animal. The resulting numbers of animals used were 22, 22 and 14 for the single anchor, single anchor-glued, and double anchor attachment techniques, respectively.

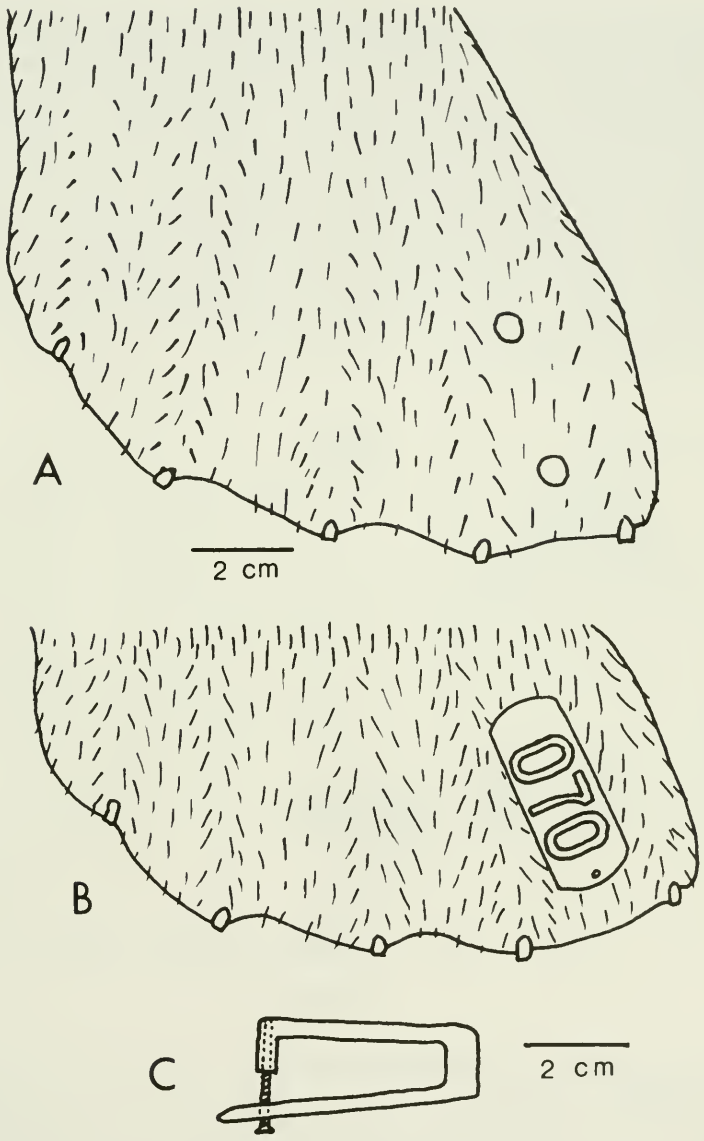

FIGURE 2. Left hind foot of a sea otter (A) with two holes punched and (B) with a modified "Temple" tag installed. (C) The predrilled open end of the tag is secured with acrylic plastic cement and a small nylon screw. Note that the bulbous end of the tag has been removed since it otherwise would press against and possibly irritate the flipper webbing.

Least squares regressions were computed for the three tagging techniques. Slopes of regressions were compared both for the three methods combined and pair wise between each method. The dependent variable was the log of the

number of tags still observed. The independent variable was days since tagging. The last day that a tag was observed served as a sample point. For this comparison all tags were assumed lost subsequent to their final observation within the allowed period (595 days). Therefore, the plot of tags still observed through time was sharply curved near the end of the time axis. This last portion of the curve poorly reflects the actual rate of tag loss because the time remaining to resight a tagged otter was short. So, no sample points were used after day 500 (Figure 3). The slope of each regression was used as a measurement of the rate of tag loss for each method. The double anchor method had a significantly different rate of tag loss from both of the other methods at $\alpha = .05$. The single anchor and single anchor-glued methods were not significantly different at $\alpha = .05$. We contend that the improved retention of the double anchor technique was responsible for these differences.

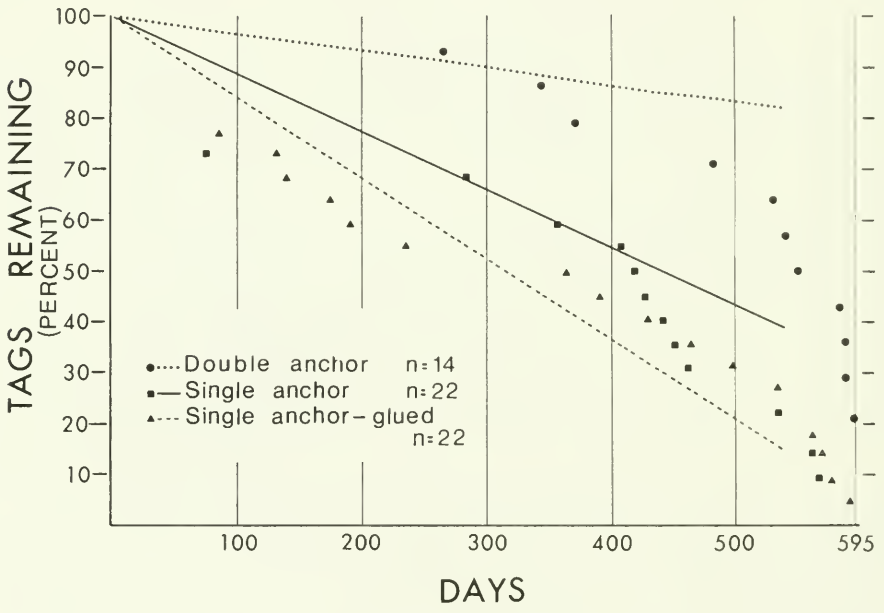

FIGURE 3. The number of tags still observed through time for three "Temple" tag attachment methods.

Permanent Tag

Despite improved retention with modified "Temple" tags we do not believe they will last the lifetime of an otter (10 to 20 years). We therefore decided to place a very small monel tag in the sea otter's ear (style 4-1005, size 1, by National Band and Tag Company). This tag's primary value will be identifying recaptured or dead sea otters that have lost their flipper tags. A sea otter's ear is relatively fleshy on both lateral aspects with a thin area down the midline. The best attachment location for this tag was in this midline area (Figure 4). Through November 1981, 196 tags have been placed in the ears of sea otters in the wild

plus several in the ears of captive otters; only two of these are known to have been lost. Due to problems restraining otters, a few of these small tags were improperly secured and some shedding might be expected. At least three live otters have been observed in the wild with ear tags but no flipper tags (i.e., both flipper tags lost). Thirteen dead otters that were previously ear tagged have been examined after a few days to over 2½ years at liberty. All of these tags were still firmly attached and no ill effects were observed. The ears and ear tags of five recaptured otters, at liberty from a few months to almost 2 years, were in excellent condition. One tag, on a captive sea otter's ear for 27 months when the animal died, still "looked like new" (James Antrim, SWSD, pers. commun.).

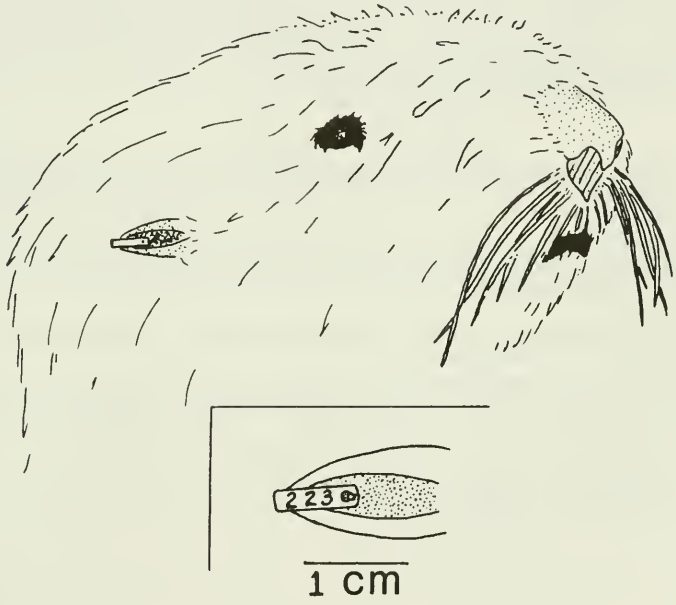

FIGURE 4. Attachment location for small monel tag.

DISCUSSION

Double anchoring appears to greatly improve tag retention. Solid colored tags in a variety of colors make field identification relatively easy. The plastic tags do not bend and pinch tissue as do some metal tags. Delong (in Hobbs and Russel ed. 1979) compared the properties of various pinniped tag materials for abrasion resistence and UV light stability and concluded that monel was superior to any plastic. Monel, although very durable, unfortunately does not allow the identification of large numbers of individuals at a distance. "Temple" tags have remained in cattle ears for seven to nine years (Lloyd Tate, Engineering Manager, Temple Tag Co., pers. commun.), but their durability after several years of sunlight, salt water, and sea otter chewing remains to be seen. To date, damage due to chewing appears to be the major shortcoming. Also, after two or three years some colors have faded, thereby confusing identifications.

The small monel tag attached to a sea otter's ear, as described, will probably function as a life-long identifying mark in most cases. A surprising additional benefit of the small ear tag is that it can sometimes be seen through a telescope and therefore used to help confirm field identifications.

ACKNOWLEDGMENTS

We wish to thank A. Johnson for providing us with our initial supply of "Temple" tags. R. Jamesom first suggested double anchoring and provided us with information on two recaptured otters and many telescope observations. L. Cornell, J. Antrim and T. Goff of Sea World allowed us to test tags on captive animals and provided us with follow-up observations. We also thank A. Baker, L. Bulluomini, S. Benech, J. Bodkin, E. Faurot, L. Ferm, M. Flippo, B. Hatfield, D. Miller, C. Ribic, L. Smith, F. Sorenson, J. Vandevere, B. Van Ness, and C. Woodhouse for making tag observations. J. Geibel and P. Law provided statistical advice. R. N. Lea reviewed the manuscript.

LITERATURE CITED

Costa, D. P. and Kooyman, G. L. 1981. Effects of oil contamination in the sea otter, *Enhydra lutris.* Pages 65–107 *in* Environmental Assessment of the Alaskan Continental Shelf. Final reports of principal investigators, vol. 10: Biological studies. (576.061 US)

Hobbs, L. and P. Russell, Ed. 1979. Report on the pinniped and sea otter tagging workshop 18–19 January 1979, Seattle, Washington. Coordinated by American Institute of Biological Sciences, Arlington, Virginia 1–48.

Kenyon, K. W. 1969. The sea otter in the Eastern Pacific Ocean. U. S. Bur. Sport Fish. and Wildl., No. Amer. Fauna, (68):1–352.

Loughlin, T. R. 1978. A telemetric and tagging study of sea otter activities near Monterey, California. National Technical Information Service, PB-289 682. p 1–64.

Odemar, M. W. and K. C. Wilson. 1969. Results of sea otter capture, tagging and transporting operations by the California Department of Fish and Game, pages 73–79 *in* Sixth Ann. Conf. on Biological Sonar and Diving Mammals, Stanford Res. Inst., Menlo Park, Calif., Proc: 1–113.

Ribic, C. A. 1981. Fall Movements and Activity Patterns of Sea Otters, *Enhydra lutris,* in California. Thesis, University of Minnesota, Minneapolis MN. p 1–124.

Wild, P. W. and J. A. Ames. 1974. A report on the sea otter, *Enhydra lutris* L., in California. California Department of Fish and Game, Mar. Res. Tech. Rep., 20:1–93.

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Photoelectronic composition by
CALIFORNIA OFFICE OF STATE PRINTING

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POSTMASTER: RETURN POSTAGE GUARANTEED
Editor, CALIFORNIA FISH AND GAME
CALIFORNIA DEPARTMENT OF FISH AND GAME
1416 NINTH ST., SACRAMENTO, CA 95814